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THESIS

MODELING THE USE OF THE AJCN IN A TACTICAL ENVIRONMENT

by

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June 2005

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The Adaptive Joint Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Node (AJCN) is a new C4ISR system with four functional capabilities: communications, signal intelligence (SIGINT), electronic warfare (EW) and Information Operations. This thesis evaluates the first three capabilities of the AJCN: communications, SIGINT and EW. Simulation is used as a time- and cost-effective way to model the AJCN's capabilities. Eleven communications and combat effectiveness MOE are used to evaluate the AJCN's performance. Point of Attack 2, a tactical simulation with an extensive database is used to replicate the AJCN and UA operations. Results of the analysis include: 1) the AJCN significantly increased friendly detection of enemy forces; 2) the AJCN significantly decreased average message transmittal time and the number of failed messages; 3) the AJCN increased the friendly force's capability to jam and intercept enemy messages.

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MODELING THE USE OF THE AJCN IN A TACTICAL ENVIRONMENT

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ABSTRACT

The Adaptive Joint Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) Node (AJCN) is a new C4ISR system with four functional capabilities: communications, signal intelligence (SIGINT), electronic warfare (EW) and Information Operations. This thesis evaluates the first three capabilities of the AJCN: communications, SIGINT and EW. Simulation is used as a time- and cost-effective way to model the AJCN's capabilities. Eleven communications and combat effectiveness MOE are used to evaluate the AJCN's performance. Point of Attack 2, a tactical simulation with an extensive database is used to replicate the AJCN and UA operations. Results of the analysis include: 1) the AJCN significantly increased friendly detection of enemy forces; 2) the AJCN significantly decreased average message transmittal time and the number of failed messages; 3) the AJCN increased the friendly force's capability to jam and intercept enemy messages.

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LIST OF ACRONYMS AND ABBREVIATIONS

AA	Assembly Area
ACTD	Advanced Concept Technology Demonstration
AI	Artificial Intelligence
AFOTEC	Air Force Operational Test & Evaluation Center
AJCN	Adaptive Joint C4ISR Node
AM	Amplitude Modulation
ANOVA	Analysis of Variance
ATTK	Attack
BA	Battlespace Awareness
BAE	British Aerospace
BN	Battalion
C2	Command and Control
C4I	Command, Control, Communications, Computers, and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAV	Cavalry
CNO	Computer Network Operations
COI	Critical Operational Issues
CONOPS	Concept of Operations
Cop	Coordination Point
COTS	Commercial Off-the-Shelf
CP	Checkpoint
CRP	Command Repeat
DAMA	Demand Assigned Multiple Access
DoD	Department of Defense
DTIC	Defense Technical Information Center
EAIII	Extended Awareness III
EPLRS	Enhanced Position Location Reporting System
EW	Electronic Warfare
FBCB2	Force XXI Battle Command, Brigade-and-Below
FM	Frequency Modulation
FOW	Fog of War
FSB	Forward Support Battalion
ft	Feet

HMMWV	High Mobility Multi-purpose Wheeled Vehicle
HQ	Headquarters
GSM	Global Standard for Mobile
IAP	Integrated Assessment Plan
ICV	Infantry Carrier Vehicle
IN	Infantry
IP	Internet Protocol
JCIDS	Joint Capabilities Integration and Development System
JFCOM	Joint Forces Command
JMUA	Joint Military Utility Evaluation
JOpsC	Joint Operations Concepts
lbs	Pounds
LMR	Land Mobile Radio
LOS	Line of Sight
MC2	Multi-sensor Command and Control
ME	Main Effort
MHz	Megahertz
MOE	Measure of Effectiveness
NAI	Named Area of Interest
NLT	No Later Than
nm	Nautical Miles
NMC	Non-mission Capable
OBJ	Objective
POA2	Point of Attack 2
Pt	Point
RCV	Receive
RF	Radio Frequency
RT	Route
SA	Situational Awareness
SATCOM	Satellite Communications
SIGINT	Signal Intelligence
SINCGARS	Single Channel Ground and Airborne Radio System
SOF	Special Operations Forces

SP	Start Point
SW	Software
TCDL	Tactical Common Data Link
TCS	Tactical Command System
TUAV	Tactical Unmanned Aerial Vehicle
UA	Unit of Action
UAV	Unmanned Aerial Vehicle
UHF	Ultra High Frequency
US	United States
USJFCOM	United States Joint Forces Command
VHF	Very High Frequency
Vic	Vicinity

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EXECUTIVE SUMMARY

To satisfy the need for information superiority on the battlefield, a BAE systems-led team of defense contractors is developing the Adaptive Joint Command, Control, Communications, Computing, Intelligence, Surveillance and Reconnaissance Node (AJCN). The AJCN has four functional capabilities: communications, signal intelligence (SIGINT), electronic warfare (EW) and information operations.

The communications capabilities of the AJCN are range extension, bridging of similar and dissimilar waveforms and global reach-back. SIGINT capabilities include electronic reconnaissance, auto recognition, geolocation and exploitation. Electronic warfare capabilities include electromagnetic jamming and electromagnetic deception.

The AJCN is capable of performing multiple missions simultaneously. The AJCN can be configured multiple ways either before or during flight to support varying missions. The payload can be installed on several platforms to include manned aircraft, unmanned aerial vehicles (UAV), and ground platforms.

In order to satisfy the need for statistical analysis, we conducted a computer simulation of AJCN missions in support of Unit of Action (UA) operations. Because computer simulations require relatively little time and money, we can evaluate multiple scenarios. The resources required make evaluating the same scenarios through actual training impractical. For this thesis, we used Point of Attack 2 (POA2) for all simulations. POA2 is a tactical simulation with a detailed and accurate database appropriate for creating new systems, such as C4I systems.

This thesis analyzes the effect of the addition of AJCN capabilities on Unit of Action operations. It determines how different capabilities are likely to influence combat operations and which capabilities provide the greatest benefit.

During this study we established four control variables: red forces, AJCN platforms, AJCN communications capabilities, and “fog of war” level. Red forces describes the type of enemy forces present in the scenario and took on two levels: conventional or insurgent (SOF). AJCN platforms represents the type of platforms present in the scenario and could have three levels: none, air only or air and ground. AJCN communications capabilities describes the type of AJCN capabilities present in our payloads and could take on two levels: voice or voice and data. Fog of war is a parameter in POA2 that varies the level of confusion on the battlefield. Fog of war was set to one of two levels: “standard” or “three.” We did a full factorial design and five replications of each combination of variables.

We developed 11 measures of effectiveness (MOE) for AJCN performance that support two functional capabilities: battlespace awareness (BA) and joint command and control (C2):

1. Force exchange ratio
2. Fractional exchange ratio
3. Fratricide
4. Acquisition rate
5. Survivability
6. Successful jamming rate
7. Red messages interception rate
8. Time to mission completion
9. Blue force persistence
10. Message transmittal time
11. Percent failed messages.

Using analysis of variance and the chi-squared test for homogeneity, our analysis found that the AJCN has a statistically and militarily significant positive impact on acquisition rate, message transmittal time, message failure rate, jamming rate and interception rate. We could not show that the AJCN had a significant impact on force exchange ratio, fractional exchange ratio, fratricide, blue force persistence, survivability, or time to mission completion.

The average acquisition rate increased from 39% in scenarios with no AJCN to 53% in scenarios with AJCN present. The average message transmittal

time decreased from 222 seconds with no AJCN present to 181 seconds with AJCN air platforms present and 170 seconds when both air and ground platforms were present. This is especially beneficial for digital units with limited bandwidth. The average message failure rate decreased from 26% to 20% when AJCN were added. Adding the AJCN also allowed blue forces to jam and intercept red messages at increased rates of .05% and 3.5% respectively.

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I. INTRODUCTION

A. BACKGROUND

The need for information superiority on the battlefield is crucial. To satisfy this requirement, a BAE Systems-led team of defense contractors is developing the Adaptive Joint Command, Control, Communications, Computing, Intelligence, Surveillance and Reconnaissance Node (AJCN). The Defense Technical Information Center (DTIC) (2005) defines the AJCN as "an open, Commercial-Off-The-Shelf (COTS) based system that can be remotely programmed on the fly to perform a variety of functions simultaneously: air-to-air assured interoperable communications, electronic warfare (EW), signals intelligence (SIGINT), and computer network operations (CNO)." The AJCN has four functional capabilities: communications, signal intelligence (SIGINT), electronic warfare (EW) and Information Operations. This thesis will evaluate the first three capabilities of the AJCN: communications, SIGINT and EW.

The Office of the Joint Chiefs of Staff has developed four functional concepts for Joint Operations Concepts (JOpsC): Battlespace Awareness (BA), Joint Command and Control (C2), Force Application and Net-Centric Operations. The AJCN is intended to support the BA and Joint C2 operational concepts for JOpsC (United States Joint Forces Command (USJFCOM), 2004).

United States Joint Forces Command (JFCOM) is conducting an exercise called Extended Awareness III (EAIII) at Fort Huachuca, Arizona in September 2005. The purpose of this exercise is to demonstrate the use of the AJCN in a tactical environment. During that exercise, JFCOM will be mounting AJCN prototypes on the Hunter Unmanned Aerial Vehicle (UAV) and the Paul Revere aircraft. JFCOM will simulate ground forces using a number of simulation tools.

Due to time and monetary constraints, JFCOM will only be able to run a limited number of missions during EAIII. With such limited data available, it will be impossible to do any sort of statistical analysis on the AJCN. Without

statistical analysis, it will be difficult to determine the actual effect the AJCN has on tactical operations.

In order to satisfy the need for statistical analysis, we conducted a computer simulation of AJCN missions in support of Unit of Action (UA) operations. Because computer simulations require relatively little time and money, we can evaluate multiple scenarios. The resources required make evaluating the same scenarios through actual training impractical.

B. AJCN OVERVIEW

Communications capabilities of the AJCN are range extension, bridging of similar and dissimilar waveforms and global reach-back. The "AJCN Advanced Concept Technology Demonstration (ACTD) Joint Concept of Operations (CONOPS)" (2004) defines range extension as the ability to extend "the range of line of sight voice and data communications hundreds of miles over various types of terrain." If two people wish to talk on FM radio, they must either have line-of-sight (LOS) or each must have LOS to an antenna set to relay on their frequency. The AJCN can be programmed to extend their communications hundreds of nautical miles without the need for LOS on the ground. Bridging of similar and dissimilar waveforms provides connectivity between disparate radios and networks. For instance, the Army and the Air Force currently have a number of communications systems that are not compatible with one another. Waveform bridging allows units using these dissimilar waveforms to communicate. Global reach-back is a type of waveform bridging. It allows any tactical radio access to a satellite communications (SATCOM) link ("AJCN ACTD CONOPS", 2004).

SIGINT capabilities include electronic reconnaissance, auto recognition, geolocation and exploitation. Electronic reconnaissance consists of "surveying the electromagnetic frequency spectrum in the battlespace" ("AJCN ACTD CONOPS", 2004). The AJCN can examine the entire frequency range of its RF receive sub-system or only a specific slice, giving commanders unprecedented situational awareness. Auto recognition is the ability to recognize emitter types. When a signal is detected, the AJCN can recognize the emitter type. This provides the warfighter with additional intelligence to consider when formulating

his course of action. Geolocation refers to the ability to determine the location of emitters operating in the battlespace. When a signal is detected, the AJCN can determine the direction from which the signal came then ascertain the location of the emitter. Exploitation is the capability to "copy and record voice and data communications." These transmissions can be copied in real time or recorded for later analysis. (JFCOM CONOPS, 2004)

Electronic warfare includes electromagnetic jamming and electromagnetic deception. Electromagnetic jamming consists of blocking or disrupting enemy emissions in the battlespace. The CONOPS defines electromagnetic deception as "radiating emissions in a manner intended to convey misleading information" to the enemy.

The AJCN is capable of performing multiple missions simultaneously. It might continuously perform electronic reconnaissance while also conducting range extension in support of maneuver units. Its software can be configured both before and during an operation. The AJCN can be configured multiple ways to support varying missions and "permits dynamic reallocation of resources … [for] different mission[s]." (BAE Systems, 2004) The payload can be installed on multiple platforms including manned aircraft (e.g. the KC-135 or Paul Revere), unmanned aerial vehicles (e.g. the Hunter or Predator), and ground platforms (e.g. the HMMWV (HUMVEE) or a civilian vehicle).

C. POINT OF ATTACK 2 OVERVIEW

For this thesis, we will use Point of Attack 2 (POA2) for all simulations. Rhoades and Gilman's (2004) thesis "Wargaming and Simulation as Tools for CONOPS Development" focused on employment of the AJCN. They investigated the possible use of several simulation packages and determined that POA2 was the best simulation on which to model the capabilities of the AJCN. POA2 was developed by Scott Hamilton in conjunction with the United States Air Force Office of Scientific Research.

The makers of POA2 describe it as a "modern tactical-level simulation that depicts combat at the platoon and individual vehicle level, with complete

depiction of supporting artillery, air strikes, electronic warfare, engineer, chemical warfare, helicopter, naval, and [psychological operations] units" (HPS Simulations, 2005). Rhoades and Gilman found the POA2 database to be more detailed and accurate than other available simulations and, therefore, more appropriate for creating new systems, such as C4I systems.

POA2 is a Windows-based program that can replicate hundreds of entities at various levels. It can simulate red and blue forces as well as neutral entities, such as civilians. Although POA2 is a Human-in-the-Loop Simulation, it can be used as a closed-loop simulation by employing its Artificial Intelligence (AI) capability. Parameters such as morale and training level can be varied for each entity. This provides more in-depth and realistic simulations. When using AI, game results are not repeatable. With identical inputs, we expect to get similar results but will likely never get the exact same outcome.

D. OBJECTIVES

This thesis will analyze the effect of the addition of AJCN capabilities on UA operations. We will determine how different capabilities are likely to influence combat operations and which capabilities provide the greatest benefit. We will also determine which of the functional capabilities (BA and Joint C2) the AJCN supports. We will accomplish this through POA2 simulations. The goal of this study is to answer the following questions:

1. How are friendly combat operations affected by the addition of AJCN capabilities?

2. Which JOpsC functional concepts are supported by the AJCN?

E. SCOPE, LIMITATIONS AND ASSUMPTIONS

1. Scope

This study will focus on the Communications, SIGINT, and EW capabilities of the AJCN. We will model two AJCN platforms: a small-scale payload and a large-scale payload. See Appendix A for specific details on each platform. The two payloads modeled will be as described in the "AJCN ACTD Phase III – Milestone 8 Brief" (2004). We will use the Hunter and Paul Revere UAVs as air

platforms and a HMMWV as a ground platform. For the purpose of this thesis, all AJCN capabilities will be as described in the “AJCN ACTD CONOPS” Draft Version 1.1. (2004)

2. Limitations

We chose to use Fort Huachuca, Arizona as the site for our simulation because it is also the location of EAIII. Fort Huachuca is a desert environment of about 400 square kilometers. Although we did not use the exact scenarios developed by AFOTEC for EAIII, we created a scenario that paralleled that used by AFOTEC. Because of the size of Fort Huachuca and the scenarios developed for EAIII, we decided that our simulation should model only a battalion-size operation.

Currently, JFCOM has defined only the Battlefield Awareness and Joint C2 functional concepts. Therefore, when addressing research question 2, we will look at only the BA and Joint C2 functional concepts.

3. Assumptions

For the purpose of our study, we adhered to the following assumptions:

- All information given by BAE systems is accurate.
- The technical capabilities of the AJCN as given by BAE systems are accurate.
- The weapons data in POA2 is accurate. Although we will be testing the scenarios to ensure they act as expected, we will not conduct a line-by-line verification of the weapons data.

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II. DATA AND METHODOLOGY

A. METHODOLOGY

DoD Pamphlet 73-3 (1993) defines critical operational issues (COI) as "[t]hose key operational concerns expressed as questions which, when answered completely and affirmatively, signify that a system or materiel change is operationally ready to transfer to full production." The "AJCN ACTD CONOPS" (2004) lists three critical operational issues:

- COI 1: Does AJCN provide separate RF functions that can be operated simultaneously?
- COI 2: Is AJCN suitable for military use?
- COI 3: Does AJCN have a positive impact on military operations?

JFCOM requested analysis of AJCN support for the Joint Capabilities Integration and Development System (JCIDS). In 2003, the Joint Chiefs of Staff approved the use of JCIDS to define their capability requirements. JFCOM (2004) describes JCIDS this way: "[u]nder JCIDS, operators and materiel providers work together early in the acquisition process to propose materiel solutions that more effectively satisfy capability shortfalls. The JCIDS supports the DoD's aim of providing equipment that is used throughout each of the US Armed Services and that best meets the needs of future warfighters." JCIDS consists of four functional capabilities:

- Battlespace Awareness (BA)
- Joint Command and Control (C2)
- Force Application
- Net-centric Operations.

JFCOM has required that the AJCN support the first two functional capabilities: BA and Joint C2. Each of these capabilities has 9 attributes. The BA attributes are:

Persistence
Agility
Reach
Spectrum
Precision

Quality
Security
Timeliness
Sharing.

The Joint C2 attributes are:

Superior Decision Making
Shared Understanding
Flexible Synchronization
Full Spectrum Integration
Shared Quality Information
Robust Networking
Simultaneous C2 Processes
Dispersed Command
Responsive and Tailorable Organizations.

The AJCN should support each BA attribute and the first six Joint C2 attributes. Each of these attributes supports at least one AJCN COI. For more details, see the "AJCN ACTD IAP."

In order to analyze these attributes, we used POA2. POA2 allows us to simulate the AJCN in a tactical scenario. We modeled different employments of the AJCN on the Hunter (low altitude UAV) and Paul Revere (high altitude aircraft) platforms as well as a ground platform (HMMWV).

We developed a tactical scenario at Fort Huachuca, Arizona that employs a portion of a UA against enemy insurgent (or SOF) and conventional forces (see Appendix B). We varied our control variables systematically to determine what impact, if any, the addition of AJCN has on a number of BA and Joint C2 attributes.

When calculating blue and red force losses, we used a firepower score. This allows different entities to contribute combat power relative to their actual firepower. For example, our simulation assigns a Stryker Infantry Carrier Vehicle (ICV) a firepower score of 23, relative to that of an infantry rifleman, set to a score of one.

B. CONTROL VARIABLES

Fog of War Level: POA2 has a parameter termed “Fog of War.” Adjusting this parameter allows the user to establish the level of confusion on the battlefield. This parameter has the following 5 levels:

- Off: All units always fully known, even if not sighted.
- Level 1: Enemy units always fully known if sighted.
- Level 2: Enemy units can be partially known if sighted.
- Level 3: Friendly unit positions not always known if moving.
- Standard: Friendly units always known, enemy are either known or not - by all friendly units. Once an enemy unit has been detected by a friendly unit, all friendly units automatically know its location and status.

AJCN Platforms: We used two different AJCN payloads in our simulation: a small payload and a large payload. The small payload weighs 270 pounds and requires 1500 watts of power. The large payload weighs 1500 pounds and requires 7500 watts of power. The specific capabilities of each payload are in Appendix A. Each payload can be mounted on a number of different platforms. We modeled the small payload as if it were installed on the Hunter UAV and HMMWV. We modeled the large payload as if it were installed on a Paul Revere multi-sensor command and control aircraft (MC2A). We chose these aircraft because they are the platforms JFCOM will use during EAIII.

AJCN Communications Capabilities: The AJCN has three communications capabilities: range extension, bridging of similar and dissimilar waveforms (waveform bridging) and global reach-back. These capabilities extend to both voice and data transmissions. Voice transmissions include traditional radio communications as well as text messaging. For the purpose of our simulation, data transmission, also known as situational awareness (SA), is in the form of FBCB2 data.

Red Forces: In order to evaluate the AJCN’s effectiveness against different enemy forces, we simulated both an insurgent force and a conventional opposing force. The insurgency was modeled as small groups of rebels with small arms, mortars and limited communications. The conventional forces were

an organized force equipped with Soviet-style weapons and communications systems.

Table 1. Control Variables and Levels

Variable	Levels	Variable Designation
AJCN Platforms	None	None
	2 small (Hunter), 1 Large (Paul Revere)	Air
	3 small (2 Hunter, 1 HMMWV), 1 Large	Air/Grnd
AJCN Communications Capabilities (All have SIGINT and EW)	Voice only	Voice
	Voice and data	Voice+Data
Red Forces	Insurgency	SOF
	Conventional forces	CIS
Fog of War Level	Standard	Std
	3	3

C. DESIGN OF EXPERIMENT

We ran a full factorial design on the above variables and levels with 5 repetitions at each combination. Table 2 shows the distribution of our scenarios. Each run of the simulation is independent of all other runs. Therefore, the below runs may be completed in any order.

Table 2. Design of Experiment

Run Numbers	AJCN Platforms	AJCN Comms Capabilities	Red Forces	Fog of War Level
1-5	None	N/A	Insurgent	Standard
6-10	None	N/A	Insurgent	3
11-15	None	N/A	Conventional	Standard
16-20	None	N/A	Conventional	3
21-25	Air Only	Voice Only	Insurgent	Standard
26-30	Air Only	Voice Only	Insurgent	3
31-35	Air Only	Voice Only	Conventional	Standard
36-40	Air Only	Voice Only	Conventional	3
41-45	Air Only	Voice & Data	Insurgent	Standard
46-50	Air Only	Voice & Data	Insurgent	3
51-55	Air Only	Voice & Data	Conventional	Standard
56-60	Air Only	Voice & Data	Conventional	3
61-65	Air & Ground	Voice Only	Insurgent	Standard
66-70	Air & Ground	Voice Only	Insurgent	3
71-75	Air & Ground	Voice Only	Conventional	Standard
76-80	Air & Ground	Voice Only	Conventional	3
81-85	Air & Ground	Voice & Data	Insurgent	Standard
86-90	Air & Ground	Voice & Data	Insurgent	3
91-95	Air & Ground	Voice & Data	Conventional	Standard
96-100	Air & Ground	Voice & Data	Conventional	3

D. MEASURES OF EFFECTIVENESS

We cannot effectively address all 15 applicable attributes using our simulation. Using the measures of effectiveness (MOE) that follow, we will address the following attributes:

- BA:

  Persistence
  Reach
  Precision
  Quality
  Timeliness
  Sharing
- Joint C2:

  Superior Decision Making
  Shared Understanding
  Full Spectrum Integration
  Shared Quality Information

MOE 1: Force Exchange Ratio

$$\frac{\text{\# Blue Force Kills}}{\text{\# Red Force Kills}} \tag{1}$$

This MOE measures if any increased situational awareness translates into greater ability for blue forces to: 1) engage red forces or 2) avoid red forces when advantageous. It supports the persistence attribute of BA and the superior decision-making attribute of Joint C2. A low force exchange ratio equates to greater blue force success. The number of blue kills is defined as the sum of lost firepower points. For example if the blue forces lose one Stryker ICV and two riflemen, the total points lost is the number of riflemen killed times the firepower score for one rifleman plus the number of Stryker ICVs lost times the firepower score for one Stryker. In this example, the number of blue kills would be 2*1+1*23=25. Red kills follow the same logic.

Data Requirements: # blue kills, # red kills

MOE 2: Fractional Exchange Ratio

$$\frac{\text{\# Blue Force Kills} \big/ \text{Initial Blue Forces}}{\text{\# Red Force Kills} \big/ \text{Initial Red Forces}} \tag{2}$$

This MOE measures the proportional blue casualties to red casualties. It supports the persistence attribute of BA and the superior decision-making attribute of Joint C2. A low fractional exchange ratio (close to zero) equates to greater blue force persistence. The initial value of blue forces is given by the sum of the firepower points following the same logic as above.

Data Requirements: # blue kills, initial blue forces, # red kills, initial red forces

MOE 3: Fratricide Ratio

$$\frac{\text{\# Blue Killed By Blue}}{\text{\# Blue Forces}} \tag{3}$$

This MOE measures the unit's success in disseminating friendly position data. It supports the sharing and persistence attributes of BA and the shared understanding and shared quality information attributes of Joint C2. A low fratricide ratio equates to greater blue force SA.

Data Requirements: # blue kills by blue, initial blue forces

MOE 4: Acquisition Rate

$$\frac{\text{\# Red Forces Detected (By Blue Forces)}}{\text{\# Red Forces}} \tag{4}$$

This MOE measures blue force situational awareness. It supports the reach and precision attributes of BA. A high acquisition rate equates to increased blue force SA.

Data Requirements: # red forces detected, # red forces

MOE 5: Survivability

$$\frac{\text{\# AJCN Platforms Destroyed}}{\text{\# AJCN Platforms Fielded}} \tag{5}$$

This MOE measures the survivability of the AJCN platforms. It supports the persistence attribute of BA. High survivability equates to greater persistence.

Data Requirements: # AJCN platforms destroyed, # AJCN platforms fielded

MOE 6: Successful Jamming Rate

$$\frac{\text{Total Time Blue Forces Successfully Jamming Red Force Comms}}{\text{Total Red Force Communication Time}} \tag{6}$$

This MOE measures the blue force's ability to jam enemy communications. It supports the reach attribute of BA. We desire a high jamming rate.

Data Requirements: amount of time each blue system is successfully jamming, amount of time each red communications system is operating

MOE 7: Red Messages Interception Rate

$$\frac{\text{\# Red Force Messages Intercepted}}{\text{\# Red Force Messages Sent}} \tag{7}$$

This MOE measures the blue force's ability to intercept red messages. It supports the precision attribute of BA. We desire a high interception rate.

Data Requirements: # red force messages successfully intercepted, # red force messages sent

MOE 8: Time to Mission Completion

$$\text{Time First Force On Objective - Mission Start Time} \tag{8}$$

This MOE measures the blue force's ability to accomplish their mission in a timely manner. It supports the precision and timeliness attributes of BA. We desire a low time to mission completion. The time the first force is on the objective is the simulation time the first blue force comes within 125 meters of the objective. It is measured to the nearest 30 seconds.

Data Requirements: mission start time, time first force on objective

MOE 9: Blue Force Persistence

$$\text{Blue Force Level At Mission Completion} \tag{9}$$

This MOE measures the number of blue forces that are mission ready. It supports the persistence attribute of BA. High blue force persistence equates to greater blue force success.

Data Requirements: # blue forces surviving until mission completion

MOE 10: Message Transmittal Time

$$\frac{\text{Total Time to Transmit All Messages (Blue)}}{\text{\# Blue Messages Transmitted}} \tag{10}$$

This MOE measures the blue force's ability to transmit information in a timely manner. It supports the timeliness attribute of BA and the superior decision-making and shared understanding attributes of Joint C2. A low transmittal time is desirable.

Data Requirements: time to transmit each blue message, # blue message transmitted

MOE 11: Percent Failed Messages

$$\frac{\text{\# Failed Messages (Blue)}}{\text{\# Attempted Messages (Blue)}} \tag{11}$$

This MOE measures the blue force ability to communicate information. It supports the quality and timeliness attributes of BA and the full spectrum integration attribute of Joint C2. A low percentage of messages that fail equates to greater blue force SA. A message failure is defined as any message that takes longer than 5 minutes to transmit or any message that must be sent by messenger or visual signal.

Data Requirements: # blue messages transmitted, # blue message transmittals that fail

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III. ANALYSIS

Two of our variables – AJCN and AJCN Communications Capability (Comms) – are closely related. We defined AJCN to be either “None” (no AJCN present in the scenario), “Air” (AJCN mounted on Hunter and Paul Revere aircraft), or “Air/Grnd” (AJCN mounted on Hunter, Paul Revere and HMMWV platforms). We defined Comms to be either “Voice” (the AJCN payload is configured to transmit and receive only voice communications), or “Voice+Data” (the AJCN payload is configured to transmit and receive both voice and data communications). By necessity the Comms variable has a third level, “None”, which signifies no AJCN are present in the scenario. Multi-collinearity arises because every time AJCN equals “None,” Comms also equals “None.” Therefore, these two terms cannot both be included in a linear regression. The ANOVA function allowed us to include both the AJCN and Comms variables. However, because we do not have a balanced design, the results are influenced by the order of the variables, and this needs to be kept in mind.

We approached this issue in several ways. First, we performed ANOVA with both our AJCN and Comms variables present. During this analysis, we used backward elimination to remove unnecessary variables. Second, we performed separate ANOVA, first without Comms as a predictor, then without AJCN. Third, we created an additional variable, OComm, which combined the AJCN and Comms variables, and performed ANOVA with the OComm variable replacing both AJCN and Comms. This single variable has five levels and represents all the information present in both the AJCN and Comms variables. Because OComm combines the AJCN and Comms variables, interactions are inherently considered and neither they nor the main effects can be separated. From these ANOVA’s, we compared all of the available models and selected the best model for our analysis.

In the following paragraphs, we will analyze MOE 4: acquisition rate in depth. The AJCN had the most striking effect on this MOE. We will then provide

a general analysis of the other MOEs. In-depth information on all MOEs can be found in Appendix C.

A. ACQUISITION RATE

Acquisition rate is defined as the number of red forces detected by the blue forces divided by the number of red forces present in the scenario. For this MOE, we were concerned with the raw number of forces and not their aggregate firepower score. A red force could be detected more than once. If a unit was detected, then lost by all blue forces, then detected again, that counted as two detections. A higher acquisition rate indicates greater blue force SA. The distribution of acquisition rate appears to be approximately normally distributed (see Figure 1).

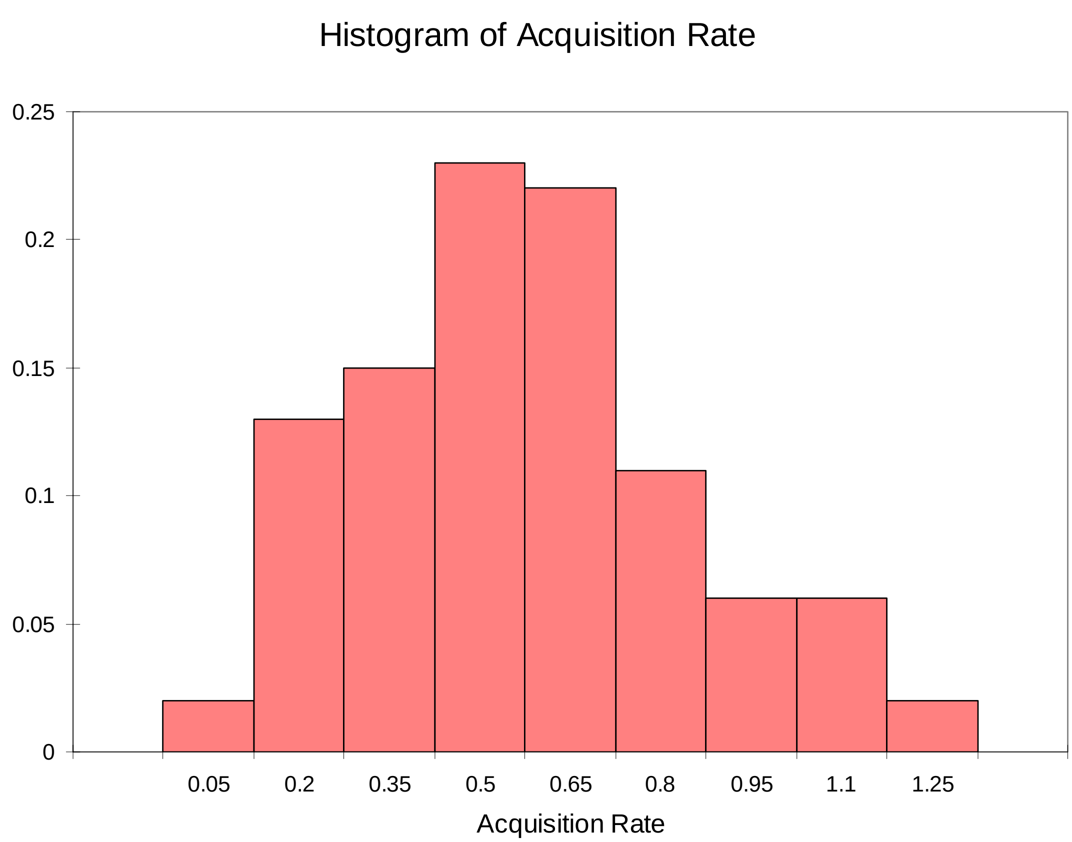

Figure 1. Distribution of Acquisition Rate

The presence of an AJCN in a scenario increased the rate at which blue forces detected red forces by over 14%. Figure 2 and Table 3 show the mean for each level of AJCN.

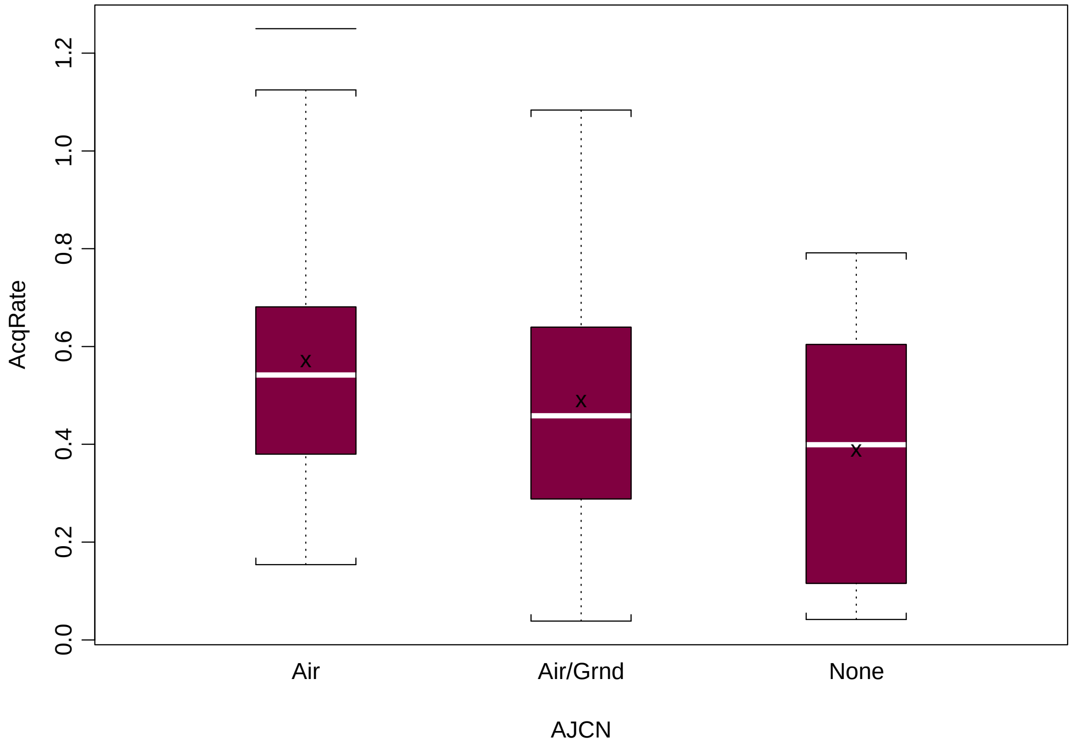

Figure 2. Boxplot of Acquisition Rate by AJCN

Table 3. Mean Acquisition Rate by AJCN

AJCN Level	Mean Acquisition Rate
None	.386
Air	.569
Air/Ground	.488

We conducted an ANOVA on Acquisition Rate. First, we used Red, AJCN, Comms and FOW as predictors and allowed all interactions. By using backward elimination, we eliminated interactions and main effects until we came up with the following model:

$$E(X_{i,j,k}) = .58 - .28 * \alpha_{SOF} + .30 * \beta_{Air} + .22 * \beta_{Air/Grnd} - .10 * \delta_{Std} - .22 * \gamma_{Air,Std} - .24 * \gamma_{Air/Grnd,Std} \quad (12)$$

Where $E(X_{ijk})$ = expected acquisition rate for a scenario with Red level i, AJCN level j and FOW level k and where:

$$\alpha_{SOF} = \begin{cases} 1, & \text{Red = SOF} \\ 0, & \text{Otherwise} \end{cases}, \quad \beta_{Air} = \begin{cases} 1, & \text{AJCN = Air} \\ 0, & \text{Otherwise} \end{cases},$$

$$\beta_{Air/Grnd} = \begin{cases} 1, & \text{AJCN = Air/Grnd} \\ 0, & \text{Otherwise} \end{cases}, \quad \delta_{Std} = \begin{cases} 1, & \text{FOW = Std} \\ 0, & \text{Otherwise} \end{cases},$$

$$\gamma_{Air,Std} = \begin{cases} 1, & \text{AJCN = Air, FOW = Std} \\ 0, & \text{Otherwise} \end{cases}, \text{ etc.}$$

We also tried replacing both AJCN and Comms with OComm. This gave us the following model:

$$\begin{aligned} E(X_{i,j,k}) = {} & .67 - .28 * \alpha_{SOF} + .19 * \beta_{Air.Voice} + .18 * \beta_{Air.Voice+Data} + .13 * \beta_{Air/Ground.Voice} \\ & + .07 * \beta_{Air/Ground.Voice+Data} - .28 * \delta_{Std} \end{aligned} \quad (13)$$

Where $\alpha_{SOF} = \begin{cases} 1, & \text{Red = SOF} \\ 0, & \text{Otherwise} \end{cases}$, $\beta_{Air.Voice} = \begin{cases} 1, & \text{OComm = Air.Voice} \\ 0, & \text{Otherwise} \end{cases}$, etc.

$$\delta_{Std} = \begin{cases} 1, & \text{FOW = Std} \\ 0, & \text{Otherwise} \end{cases}$$

Figures 3 and 4 show that both models appear to have normally distributed residuals.

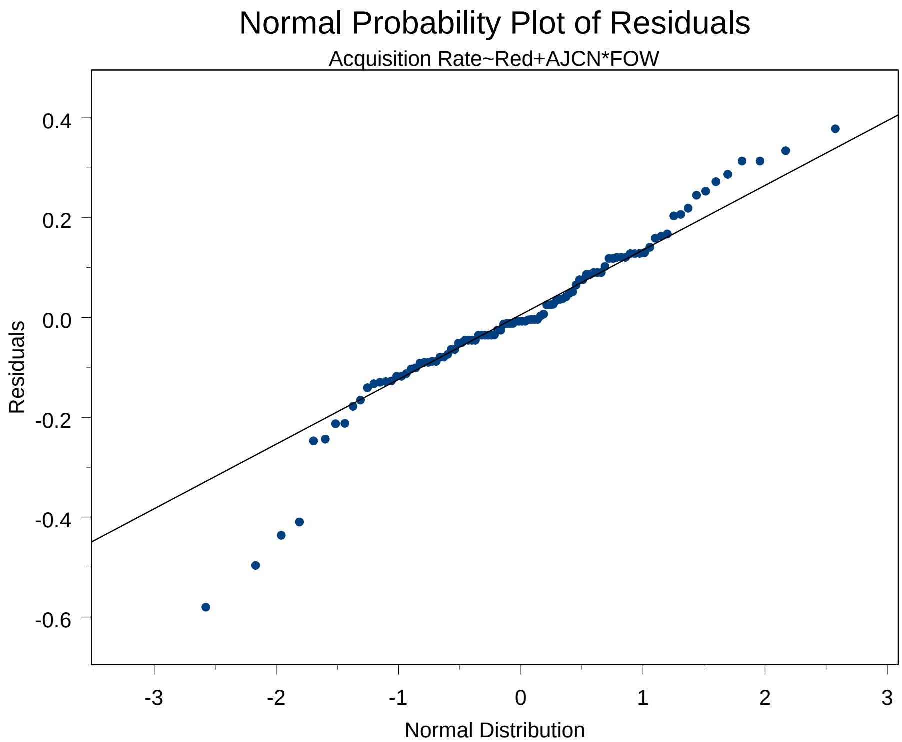

Figure 3. Normal Probability Plot: Acquisition Rate~Red+AJCN*FOW

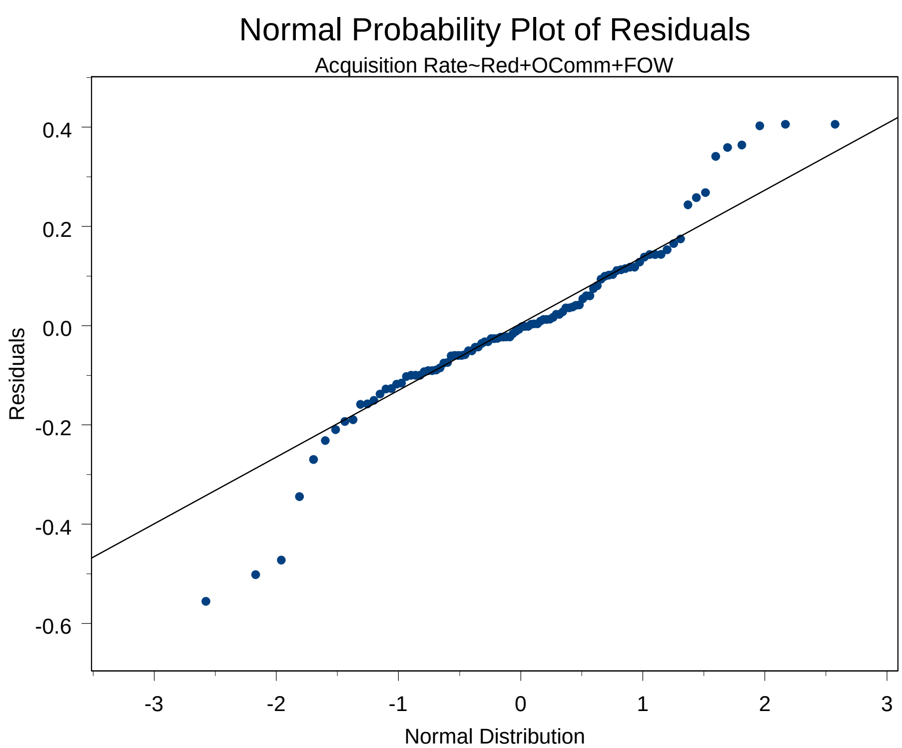

Figure 4. Normal Probability Plot: Acquisition Rate~Red+OComm+FOW

When checking for equal variance, we found that both sets of residuals appear to be heteroscedastic (Figures 5 and 6). In both models the variance increases as the predicted value for acquisition rate increases.

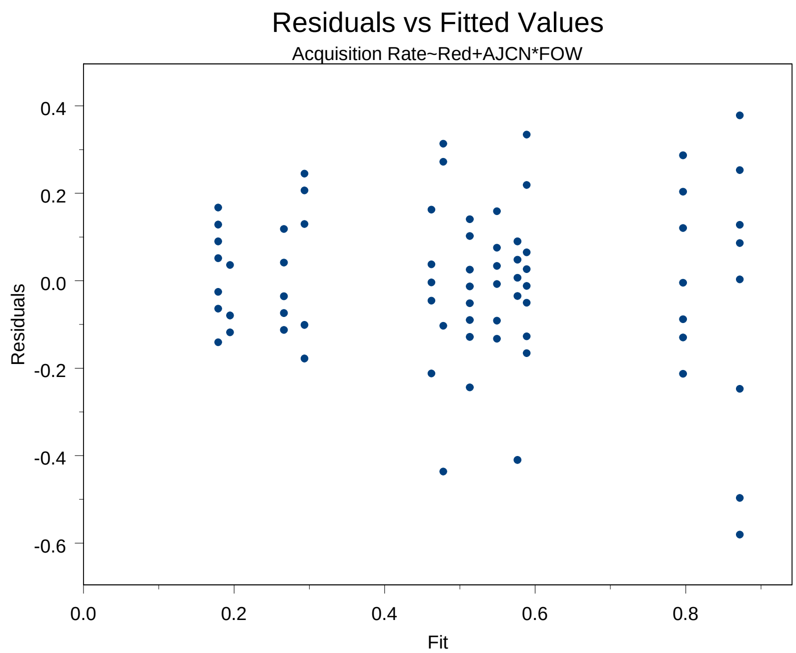

Figure 5. e_i vs $\hat{y}_i$:Acquisition Rate~Red+AJCN*FOW

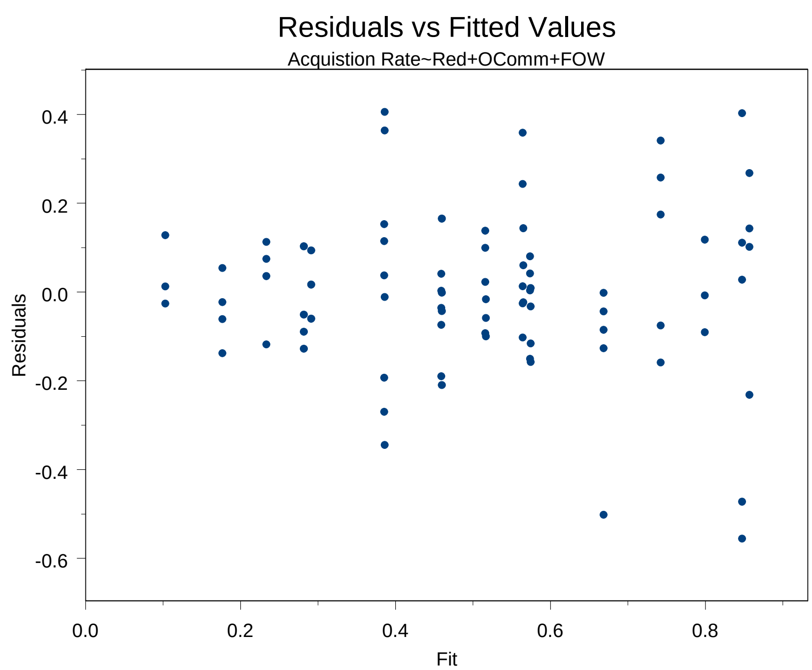

Figure 6. e_i vs $\hat{y}_i$:Acquisition Rate~Red+OComm+FOW

By transforming our response variable from acquisition rate to the square root of acquisition rate, we eliminated the heteroscedasticity (Figure 7). This transformation also eliminated the need for interaction terms.

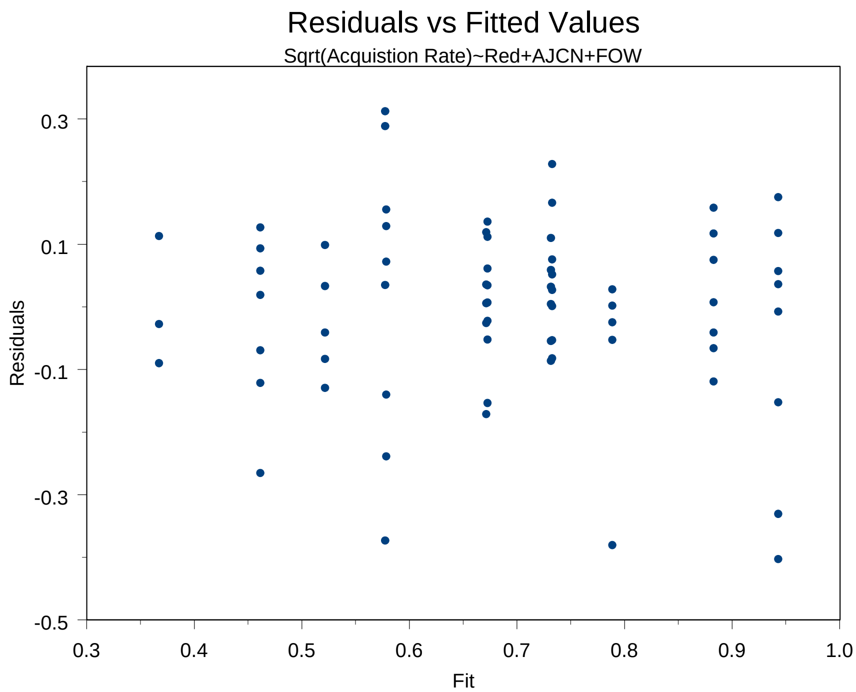

Figure 7. e_i vs $\hat{y}_i : \sqrt{Acquisition\ Rate}$ ~Red+AJCN+FOW

Our new model becomes:

$$E(X_{i,j,k}) = .79 - .21 * \alpha_{SOF} + .15 * \beta_{Air} + .09 * \beta_{Air/Grnd} - .21 * \delta_{Std} \tag{14}$$

Where $x_{i,j,k} = \sqrt{\text{Acquisition Rate}_{\text{for observation with Red level i, AJCN level j, and FOW level k}}}$

This model also appears to have residuals that are not too non-normal (See Figure 8).

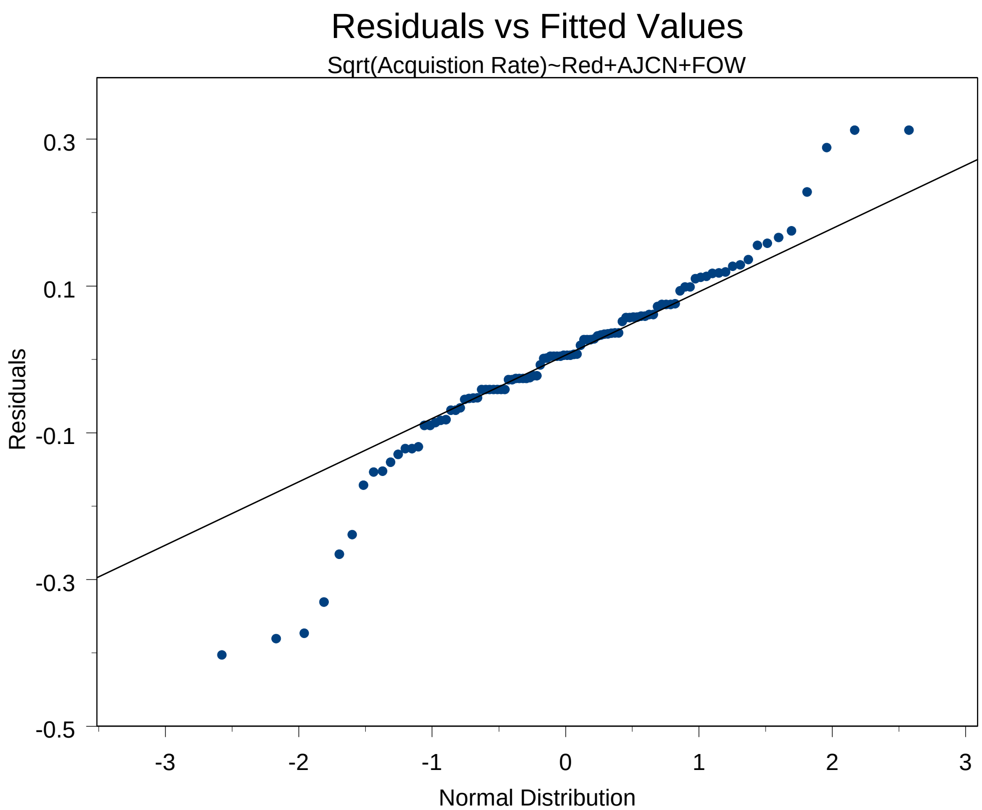

Figure 8. Normal Probability Plot: $\sqrt{\textit{Acquisition Rate}}$ ~Red+AJCN+FOW

Because we believe that any effect between Comms and AJCN is additive, we selected equation (14) as our model. This model shows a more clear relationship between AJCN and Acquisition Rate. While this model is harder to interpret than equation (12), what we lose in interpretability we gain in validity. Table 4 shows the S-PLUS output for this model. For additional information, such as estimated coefficients, see Appendix C.

Table 4. ANOVA Output for Acquisition Rate

```
       *** Analysis of Variance Model ***

       Short Output:
       Call:
          aov(formula = AcqRateSqrt ~ Red + AJCN + FOW, data = poa.out, qr = T,
na.action = na.exclude)

       Terms:
                            Red     AJCN      FOW Residuals
        Sum of Squares 1.104037 0.318895 1.114913  1.585716
       Deg. of Freedom        1        2        1        95

       Residual standard error: 0.1291966
       Estimated effects may be unbalanced

       Type III Sum of Squares
                 Df Sum of Sq  Mean Sq  F Value        Pr(F)
             Red  1  1.104037 1.104037 66.14264 0.0000000000
            AJCN  2  0.318895 0.159447  9.55247 0.0001659248
             FOW  1  1.114913 1.114913 66.79424 0.0000000000
       Residuals 95  1.585716 0.016692
```

With an $\alpha = .05$, those scenarios with only air platforms present or with air and ground platforms present had a significantly higher rate of detection than scenarios with no AJCN present (see Figure 9).

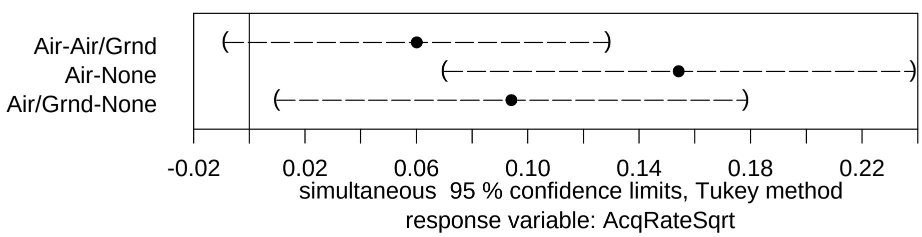

Figure 9. 95% Confidence Interval for Mean Acquisition Rate by AJCN

B. SIGNIFICANT CONTRIBUTIONS OF THE AJCN

In addition to acquisition rate, the AJCN significantly affected the successful jamming rate and red message interception rate. This is both logical and expected. Without the AJCN, the blue forces did not have any equipment capable of jamming or intercepting red messages.

The AJCN also had a significant positive effect on the average message transmittal time and the number of failed messages. The average time to transmit a message without any AJCN present was 222 seconds. With the addition of AJCN air platforms the average transmittal time decreased to 181.

That time decreased to 170 seconds when both air and ground platforms were present. This decrease in time is critical to digital units with limited bandwidth. The average proportion of undelivered messages without an AJCN was 30%. The addition of an AJCN decreased that percentage to 20%. For additional information on these MOE, see Appendix C.

C. OTHER MOE

Our simulation did not show that the addition of AJCN significantly impacted the blue force exchange or fractional exchange ratios. The addition of AJCN also did not impact the number of fratricide incidents. At first look, it appeared that the AJCN significantly increased blue force persistence. The number of blue forces (in firepower score) remaining at mission completion was significantly higher when AJCN were present. However, this data is misleading because more blue forces were also present at the start of the mission in scenarios with AJCN. After considering this, a more appropriate measure seems to be the percent of blue forces persisting to mission completion. AJCN were not a significant factor in this MOE.

The addition of a ground platform significantly increased the percentage of AJCN remaining at mission completion. However, this data is not normally distributed. A large number of observations are zero and the others take on a limited number of values. A more appropriate test is the Chi-squared test for homogeneity of AJCN loss rates across all other factors. This test revealed that there is no significant difference in survivability when a ground platform is present.

The mission completion time was defined as the simulation time when the first blue force reached the objective, measured in 30-second increments. We discovered after analyzing our simulation results that this time never varied by more than 30 seconds. This can be explained by the scenario. Because the blue force was never overwhelmed by the red force, they continued to move toward the objective and the first force reached the objective at approximately the same time for each replication of the simulation. If the scenario incorporated an overwhelming red force, this would likely not be the case. Additionally, a real life

unit might chose to stop and provide aid to its casualties instead of continuing on to the objective. Another way to define this MOE would be to record the time when 100% of all committed forces have arrived at the objective. This would likely show more variance in mission completion time. Even though we found statistical significance in evaluating this MOE, it is unlikely that 30 seconds would be militarily significant when executing a deliberate attack. For additional information on these MOE, see Appendix C.

D. SUMMARY

Our simulation showed the addition of the AJCN had a statistically and militarily significant positive impact on acquisition rate, message transmittal time, message failure rate, jamming rate and interception rate. We could not show that the AJCN had a significant impact on force exchange ratio, fractional exchange ratio, fratricide, blue force persistence, survivability, or time to mission completion.

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IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Our POA2 simulation measured and tested 11 MOEs that we developed for the AJCN. These MOE support ten JCIDS functional capability attributes. Our simulation showed that the AJCN had a significant positive impact on the following MOE:

Acquisition Rate
Message Transmittal Time
Message Failure Rate
Jamming Rate
Red Message Interception Rate.

The average acquisition rate increased from 39% in scenarios with no AJCN to 53% in scenarios with AJCN present. The average message transmittal time decreased from 222 seconds with no AJCN present to 181 seconds with AJCN air platforms present and 170 seconds when both air and ground platforms were present. The average message failure rate decreased from 26% to 20% when AJCN were added. Adding the AJCN also allowed blue forces to jam and intercept red messages at rates of .05% and 3.5% respectively.

The MOE influenced by the AJCN support the following BA and Joint C2 attributes:

Reach
Precision
Timeliness
Quality
Superior Decision Making
Shared Understanding
Full Spectrum Integration.

These attributes support both the BA and Joint C2 functional capabilities and all three COI for the AJCN.

For the other seven MOE, our simulation could detect no statistically or militarily significant difference when the AJCN was present. This does not mean no difference is present. Our scenario was a small-scale tactical one. It was located at Fort Huachuca, Arizona, an approximately 20km x 20km area, with

mostly desert terrain. It included only forces from a single infantry brigade. This location and scenario were chosen because they were similar to what JFCOM will demonstrate at EAIII. However, the AJCN's contributions might be more detectable under different conditions.

B. RECOMMENDATIONS

Any future AJCN simulation should consider the following recommendations.

- Conduct simulations at the tactical level that span greater distances and involve more restrictive terrain.
- Include forces not indigenous to the unit, especially inter-service forces (Air Force, etc.) with disparate communications.
- Expand the scenario to a strategic level mission with multiple services in multiple locations.
- Include a scenario where red force capabilities are likely to overwhelm the blue force.
- When measuring blue force time to mission completion, use the time at which all dedicated blue forces have reached the objective. (The ability to measure this is currently being incorporated into POA2.)

The AJCN's capabilities will be more clearly visible in these situations. Simulation is a useful tool and can be especially beneficial in a situation where only limited live testing is feasible. Incorporating the above recommendations will increase the benefits of conducting additional simulations.

APPENDIX A. AJCN SYSTEM CHARACTERISTICS

<u>Small Scale Payload (Hunter, HMMWV)</u>
Swap: 270 lbs, 1500 watts (managed to 1000 watts)
RCV Bandwidth: 4x25 MHz tuners, 100 MHz total
Frequency Range:

- Transmit: 40-450 MHz, 902-928 MHz, 1800-2000 MHz
- Receive: 20-3000 MHz

Simultaneous Channels: 5 transmit channels (3 SW and 2 Federated)
<u>Communications Waveforms</u>

- VHF AM/FM
- SINCGARS
- UHF AM/FM
- LMR/ Public Service (VHF/UHF AM&FM)
- Wireless IP Crosslink @ ~100 kbps (F)
- EPLRS CRP (TUAV) (F)
- GSM

Communications Range:

- 55-100 nm @ 15,000 ft (Air-Ground)
- 60 nm @ 15,000 ft (Air-Air)
- LOS (Ground-Ground)

SIGNIT: 20-3000 MHz

- **Functions:** Electronic Reconnaissance, Auto Recognition, Geolocation (<220 MHz), Exploitation
- **Signal Types:** TCS

EA/IO: Jamming

<u>Large Scale Payload (Paul Revere)</u>
Swap: 1500 lbs, 7500 watts
RCV Bandwidth: 16x25 MHz tuners, 400 MHz total
Freq Range:

- Transmit: 30-2000 MHz, Ku (Federated TCDL)
- Receive: 20-3000 MHz, Ku (Federated TCDL)

Simultaneous Channels: 15 transmit channels (10 SW and 5 Federated)
<u>Communications Waveforms</u>

- VHF AM/FM
- SINCGARS
- UHF DAMA SATCOM (F)
- LMR/ Public Service (VHF/UHF AM&FM)
- Wireless IP Crosslink @ ~100 kbps (F)
- EPLRS (F)
- GSM
- Link 16 (F)
- HaveQuick II (F)

- TCDL @10.71 Mbps (F)

Communications Range:

- 60-140 nm @ 30,000 ft (Air-Ground)
- 55-300 nm @ 30,000 ft (Air-Air)

SIGNIT: 20-3000 MHz

- **Functions:** Electronic Reconnaissance, Auto Recognition, Geolocation, Exploitation
- **Signal Types:** TCS

EA/IO: Jamming

All information in this appendix is from AJCN ACTD Phase III – Milestone 8 JMUA Demonstrations, Volume I [Ref. 1].

APPENDIX B. TACTICAL SCENARIOS

The following pages give course of action statements and locations for all company level and higher units in our simulation. This information was provided to HPS Simulations and was used to build the scenarios.

A. BASE SCENARIO

Units:

BN: 2-3 IN Battalion (Stryker/Bradley)
  Companies:
    C/2-3IN Company (Stryker/Bradley)
    B/1-14 CAV Troop (Stryker/Bradley)
    296 Forward Support Battalion (FSB)

Locations:

AA Olympia (start point) 667836 Vic. air landing strip
OBJ Dog 629831
RT Gold-
  SP- AA Olympia
  CP1- 660841
  CP2- 647846
  CP3- 644867
  CP4- 620880
  CP5-594869
  CP6- 595898
ATTK Position Doug – 636834
Support by Fire- 630824
Pt Ambush 1 – 624822
Area Ambush 2- 622843
Area Ambush 3- 633842
Zone Alpha - Coordination Point (cop) 1- 605850
  Cop 2- 595900
  Cop 3- 630902
  Cop 4- 646880
Zone Bravo – Cop 1- 605850
  Cop 2- 595900
  Cop 5- 560897
  Cop 6- 561859
Zone Charlie- cop 1- 605850
  Cop 6- 561859
  Cop 7- 573827
  Cop 8- 610850
Zone Delta- cop 1- 605850
  cop 4- 646880
  cop 8-610820

AA- 667836

Enemy locations:

OBJ Dog- 629831
NAI 3: (586841)
NAI 2: (577891)
NAI 1: (605886)

2-3 IN battalion Mission:

2-3IN conducts a hasty attack NLT 1200 APR 05 to destroy enemy insurgents vicinity OBJ Dog (629831, Village of Towerville) in order to maintain logistical operations on RT Gold.

COA statement: BN

The purpose of this operation is to maintain logistical operations on RT Gold. We will accomplish this by conducting an envelopment of OBJ Dog. The decisive point of this operation will be securing a foothold on OBJ Dog. One infantry company, the BN main effort, will conduct a raid to destroy OBJ Dog in order to maintain logistical operations on RT Gold. One cav troop, supporting effort, will conduct area reconnaissance of Zone A, B, C to cover OBJ Dog in order to prevent the enemy from massing reinforcements against the BN Main effort. The purpose of artillery is to fix enemy insurgent forces on OBJ Dog in order to support the main effort's assault. The purpose of engineers is to facilitate movement along Axis of Advance Silver in order to pass the main effort onto OBJ Dog. The endstate of this operation is all enemy destroyed on OBJ Dog NLT (attack time + 4 hrs), OBJ Dog secure, and all forces withdrawn back to AA Olympia.

COA statement: C/2-3 IN

The purpose of this operation is to maintain logistical operations on RT Gold. We will accomplish this by conducting an envelopment of OBJ Dog. The decisive point of this operation will be securing a foothold on OBJ Dog. One platoon, the company main effort, will conduct a raid to destroy enemy insurgents on OBJ Dog in order to maintain logistical operations on RT Gold. One platoon, supporting effort, will conduct a support by fire vic. SBF 1(630824) to suppress enemy forces in order to allow the main effort to assault the objective. One platoon, supporting effort, will conduct an area ambush (vic. 624822,622843,

633842) to secure OBJ Dog in order to prevent the enemy from massing reinforcements against the main effort. The purpose of company mortars will be to fix enemy forces on OBJ Dog and prevent their retreat from the main effort. The endstate of this operation is all enemy destroyed on OBJ Dog, all forces consolidated on the objective and prepared to withdraw back to AA Olympia.

COA B/1-14 CAV:

The purpose of this operation is to prevent the enemy from massing reinforcements against the BN Main effort. We will accomplish this by conducting three zone recons. The decisive point will be detecting any insurgent teams in sector. One platoon, the troop main effort, will conduct zone recon to cover Zone A in order to prevent the enemy from massing reinforcements (from the north) against the main effort. One platoon, supporting effort, will conduct zone recon to cover Zone B in order to prevent the enemy from massing reinforcements (from the northwest) against the company main effort and the BN ME. One platoon, supporting effort, will conduct zone recon to cover Zone C in order to prevent the enemy from massing reinforcements (from the west against the BN ME. The purpose of fires will be to prevent enemy movement along routes to OBJ Dog. The purpose of engineers will be to maintain clearance of routes in sector A, B, C. The endstate of this operation is the BN main effort safe passage back to AA Olympia.

Enemy locations:

OBJ Dog: (629831)
Size: insurgent team and HQ (10 men)
communications hub, barracks, intelligence, some weapons

NAI 1: (605886)
Size: insurgent team (7-8men)
weapons cache, 82mm mortar

NAI 2: (577891)
Size: insurgent team (7-8 men)
weapons cache, bunker

NAI 3: (586841)
Size: insurgent team (7-8 men)
Weapons cache, training camp

Enemy COA:

The purpose of enemy insurgents is to disrupt logistics on RT Gold and diminish local support for the American occupation. They will accomplish this by conducting ambushes on convoys of 296 FSB. The decisive point of their operation is the destruction of enough 296 logistical vehicles along RT Gold in order to disrupt 2-3IN offensive operations. One insurgent team and HQ vic. OBJ Dog, main effort, will destroy vehicles along RT Gold and OBJ Dog in order to disrupt logistics on RT Gold and diminish local support for the American occupation. One insurgent team vic NAI 1, supporting effort, will provide indirect fires to disrupt convoys along RT Gold to allow the main effort to destroy logistical vehicles. One insurgent team vic NAI 2, supporting effort, will secure hilltop and guard a weapons cache in order to resupply the main effort and prevent US forces from attacking the insurgent main effort from the west. One insurgent team, vic NAI 3, supporting effort, will secure a hilltop and train new recruits in order to provide trained fighters to the main effort along RT Gold. The purpose of enemy fires is to disrupt convoys along RT Gold. The purpose of any enemy engineering effort will be to fix 296 convoys along RT Gold with the use of IED's, allowing the main effort to conduct ambushes. The endstate of their operation is American offensive capability minimized, Americans fixed in AA Olympia, local citizens joining the American resistance.

B. CONVENTIONAL FORCES SCENARIO

Units: No change

Locations: No change

Enemy locations: No change

2-3 IN Battalion Mission:

2-3IN conducts hasty attack NLT 1200 APR 05 to destroy enemy platoon vicinity OBJ Dog (629831, Village of Towerville) in order to maintain logistical operations on RT Gold.

COA statement: BN No change

COA statement: C/2-3 IN

The purpose of this operation is to maintain logistical operations on RT Gold. We will accomplish this by conducting an envelopment of OBJ Dog. The

decisive point of this operation will be securing a foothold on OBJ Dog. One platoon, the company main effort, will conduct a raid to destroy enemy forces on OBJ Dog in order to maintain logistical operations on RT Gold. One platoon, supporting effort, will conduct a support by fire vic. SBF 1(630824) to suppress enemy forces in order to allow the main effort to assault the objective. One platoon, supporting effort, will conduct an area ambush (vic. 624822,622843, 633842) to secure OBJ Dog in order to prevent the enemy from massing reinforcements against the main effort. The purpose of company mortars will be to fix enemy forces on OBJ Dog and prevent their retreat from the main effort. The endstate of this operation is all enemy destroyed on OBJ Dog, all forces consolidated on the objective and prepared to withdraw back to AA Olympia.

COA B/1-14 CAV:

The purpose of this operation is to prevent the enemy from massing reinforcements against the BN Main effort. We will accomplish this by conducting three zone recons. The decisive point will be detecting any recon teams in sector. One platoon, the troop main effort, will conduct zone recon to cover Zone A in order to prevent the enemy from massing reinforcements (from the north) against the main effort. One platoon, supporting effort, will conduct zone recon to cover Zone B in order to prevent the enemy from massing reinforcements (from the northwest) against the company main effort and the BN ME. One platoon, supporting effort, will conduct zone recon to cover Zone C in order to prevent the enemy from massing reinforcements (from the west against the BN ME. The purpose of fires will be to prevent enemy movement along routes to OBJ Dog. The purpose of engineers will be to maintain clearance of routes in sector A, B, C. The endstate of this operation is the BN main effort safe passage back to AA Olympia.

Enemy locations:

OBJ Dog: (629831)
  Size: IN platoon (19 men)
    AK-47, PG-26, RPG-18, hand grenades
NAI 1: (605886)
  Size: recon team (1 Mortar, 1 BRDM)
    BRDM-2, 82mm mortar
NAI 2: (577891)

Size: recon team (1 BRDM)
BRDM-2
NAI 3: (586841)
Size: recon team (1BRDM)
BRDM-2

Enemy COA:

The purpose of enemy forces is to disrupt logistics on RT Gold and diminish local support for the American occupation. They will accomplish this by conducting ambushes on convoys of 296 FSB. The decisive point of their operation is the destruction of enough 296 logistical vehicles along RT Gold in order to disrupt 2-3IN offensive operations. One infantry platoon vic. OBJ Dog, main effort, will destroy vehicles along RT Gold and OBJ Dog in order to disrupt logistics on RT Gold and diminish local support for the American occupation. One recon team vic NAI 1, supporting effort, will provide indirect fires to disrupt convoys along RT Gold to allow the main effort to destroy logistical vehicles. One recon team vic NAI 2, supporting effort, will secure hilltop and guard a weapons cache in order to resupply the main effort and prevent US forces from attacking the main effort from the west. One recon team, vic NAI 3, supporting effort, will secure a hilltop and provide rear security to the main effort along RT Gold. The purpose of enemy fires is to disrupt convoys along RT Gold. The purpose of any enemy engineering effort will be to fix 296 convoys along RT Gold, allowing the main effort to conduct ambushes. The endstate of their operation is American offensive capability minimized, Americans fixed in AA Olympia, local citizens joining the American resistance.

Figures 10, 11 and 12 are the blue operations overlays for blue forces, red insurgent forces and red conventional forces respectively.

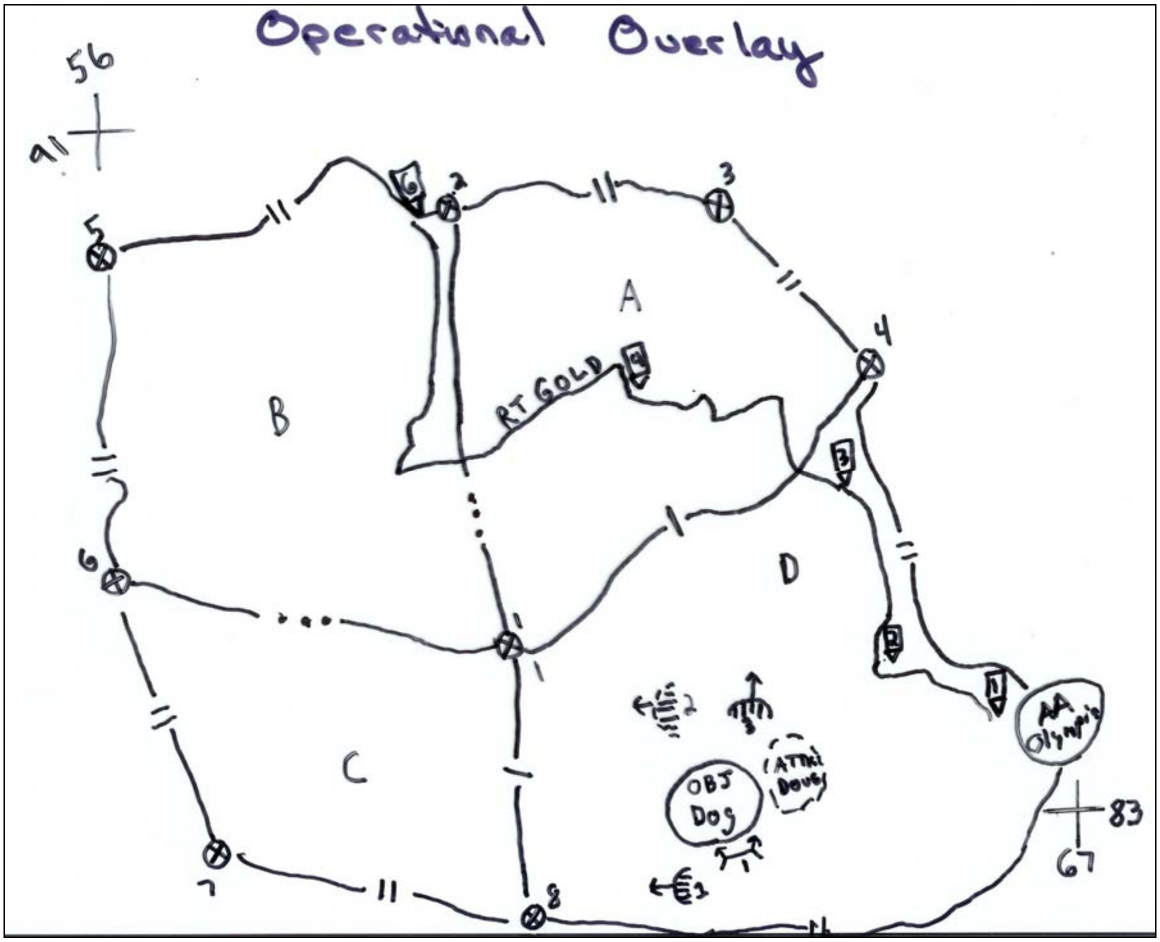

Figure 10. Operational Overlay

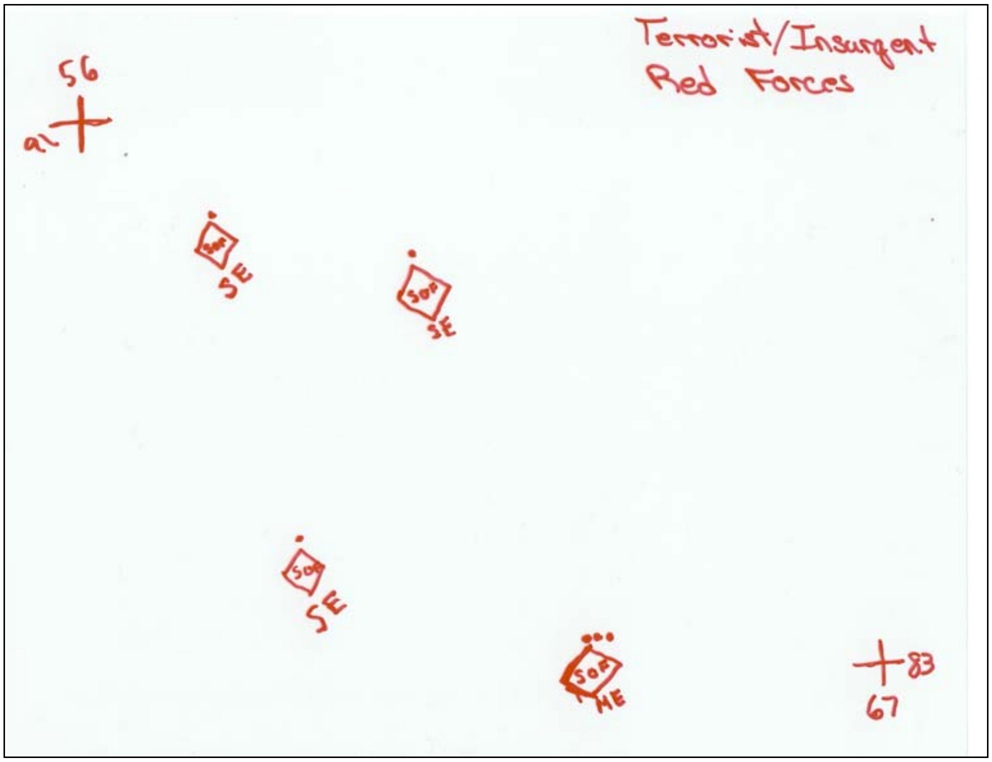

Figure 11. Insurgent Overlay

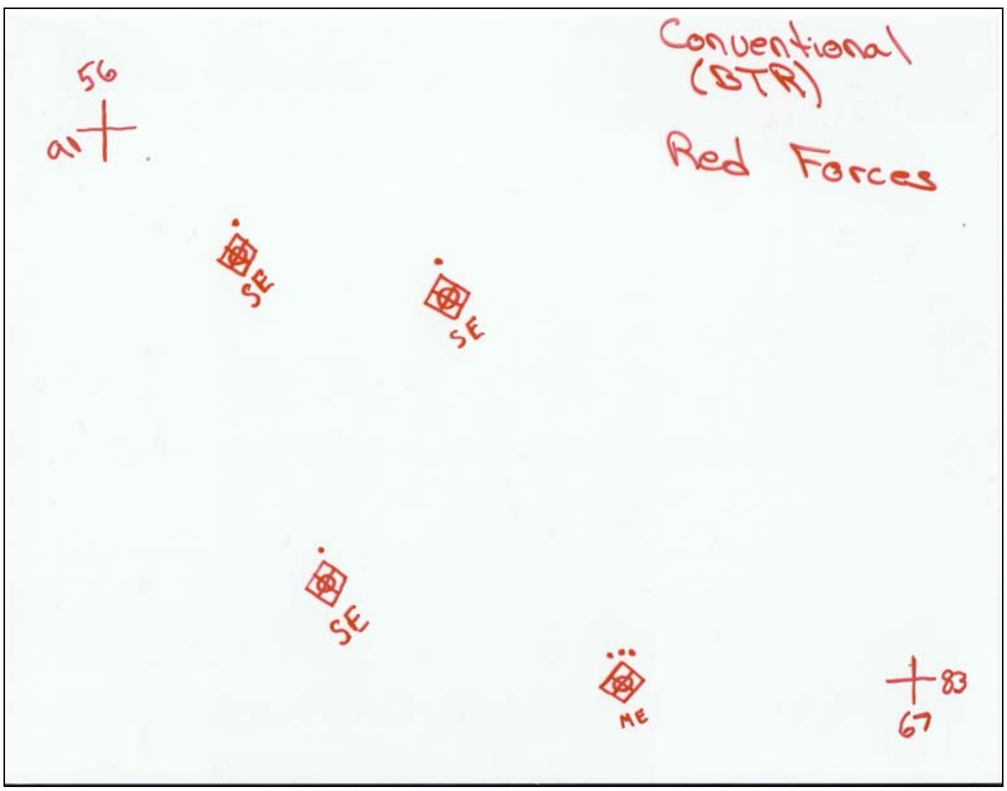

Figure 12. Conventional Forces Overlay

APPENDIX C. ADDITIONAL STATISTICAL ANALYSIS

A. MOE 1: FORCE EXCHANGE RATIO

Force exchange ratio is the number of blue forces killed (in firepower score) divided by the number of red forces killed (in firepower score). In Figure 13, this variable is clearly not normally distributed. In fact, we have a large number of observations that are zero.

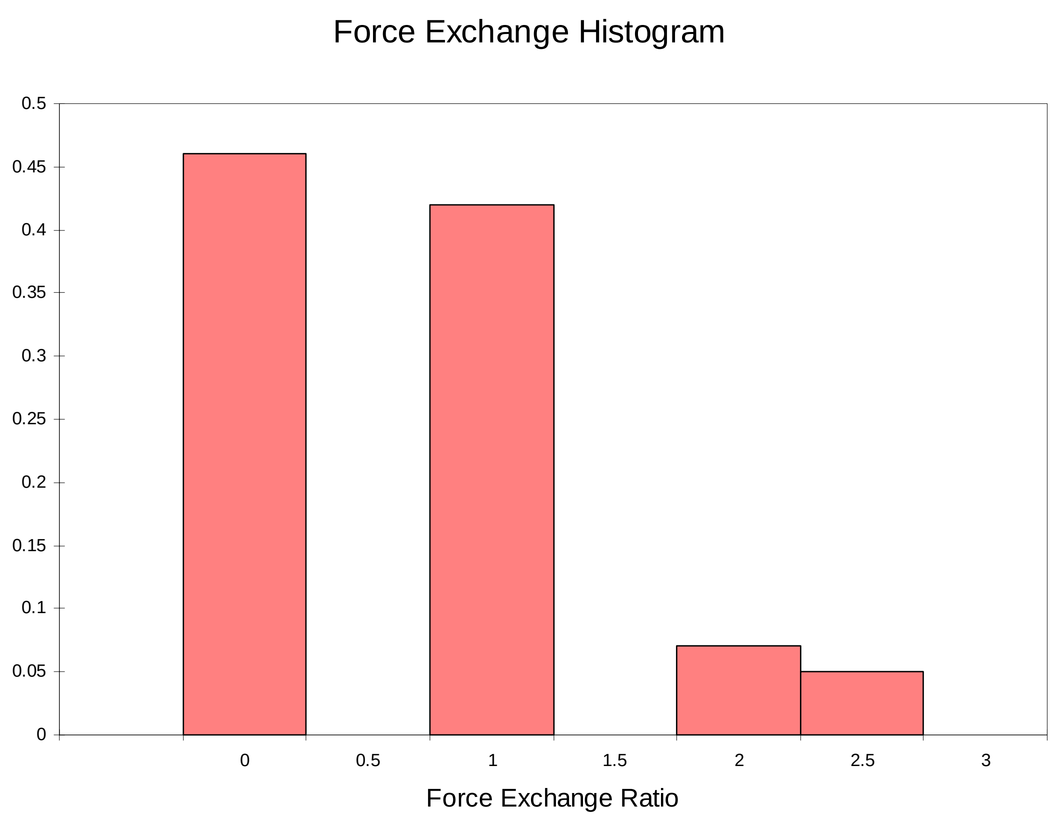

Figure 13. Distribution of Force Exchange Rate

Because we were trying to detect a relationship among multiple predictors, we conducted analysis of variance testing. However, ANOVA relies on the assumption that each treatment distribution is normally distributed and all have equal variance σ^2. Diagnostic plots from our model confirm what our histogram showed us: the residuals do not look normal (Figure14). Our data is also clearly

not homoscedastic (Figure 15). The assumptions required for ANOVA are not valid.

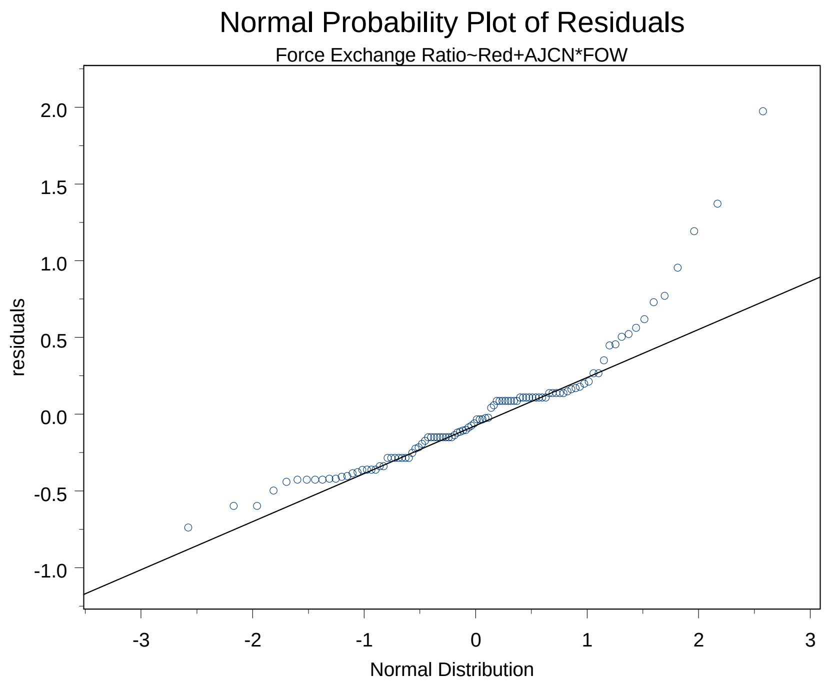

Figure 14. Normal Probability Plot: Force Exchange Ratio~Red+AJCN*FOW

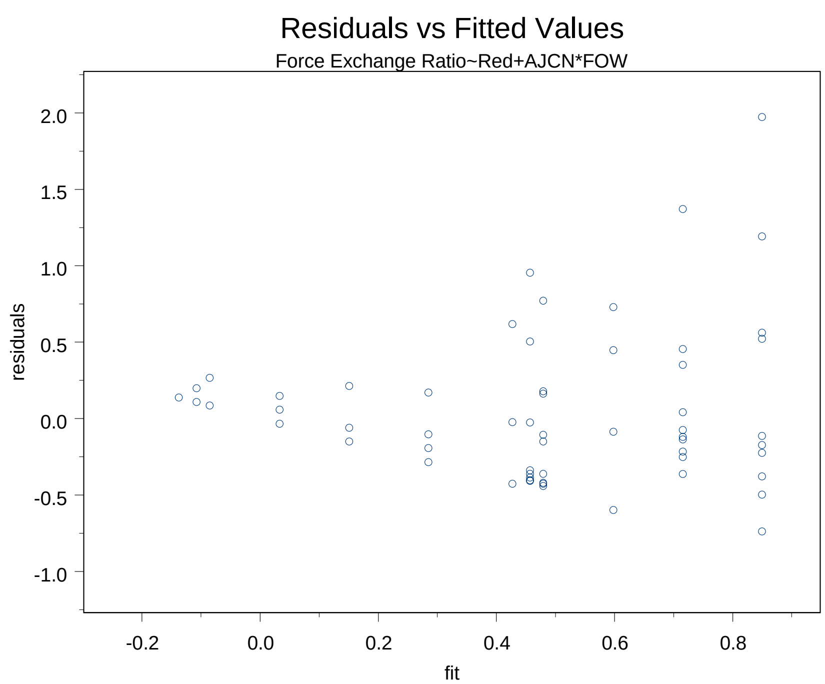

Figure 15. e_i vs $\hat{y}_i$: Force Exchange Ratio~Red+AJCN*FOW

Because the type of red forces was so significant to the force exchange ratio, we decided to split our data set and analyze each type of red force separately. However, the models generated by the split data sets had the same issues as our original model; we still did not meet the assumptions for ANOVA.

Table 5. Blue Forces Killed by AJCN

AJCN / Blue Forces Killed	0	≥ 1
None	13	7
Air	16	24
Air/Grnd	16	24

Since we had such a high number of observations with a force exchange ratio of zero, we decided to categorize our responses into two categories: those where no blue forces were killed and those where at least one blue force was killed. Assigning those responses by AJCN gave us Table 6. A Chi-squared test for homogeneity on this table gave us a p-value of .13.

H_o: $p_{none,0}=p_{air,0}=p_{air/grnd,0}$ and $p_{none,1}=p_{air,1}=p_{air/grnd,1}$

H_a: $p_{ij} \neq p_{kj}$ for some *j* and for some pair *i* and *k*

At $\alpha = .10$, we would fail to reject the null hypothesis that the probability of being in class *j* is the same for all populations (none, air and air/grnd). We can detect no difference in force exchange ratio based on the type of AJCN in a scenario.

B. MOE 2: FRACTIONAL EXCHANGE RATIO

Fractional exchange ratio is the percentage of blue forces killed (in firepower score) divided by the percentage of red forces killed (in firepower score). Figure 16 shows this variable also does not look normally distributed. Again, we have a large number of observations that are zero. This is not surprising; the force exchange ratio and fractional exchange ratio are closely related. They both consider the number of blue and red forces killed.

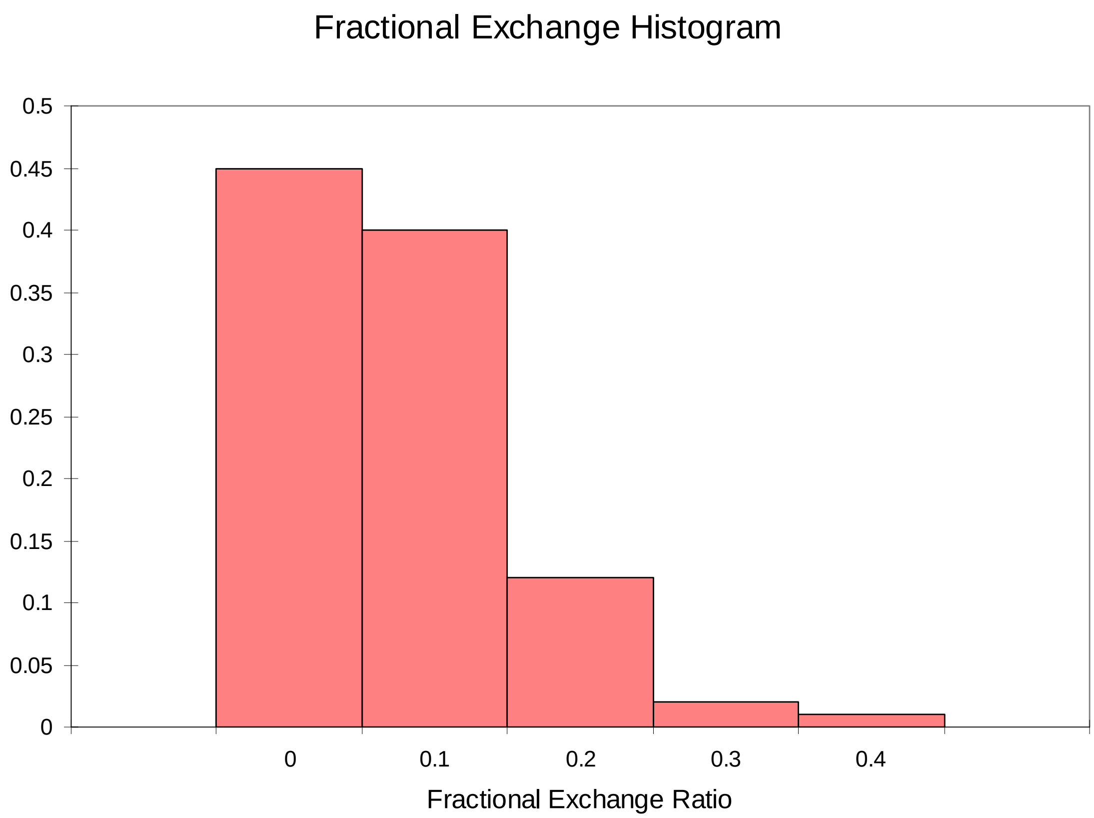

Figure 16. Distribution of Fractional Exchange Ratio

When checking our assumptions we had the same problems we had with MOE 1: non-normality and heteroscedasticity. Again, we tried splitting this data set on the type of red forces but received the same results as with force exchange ratio. Categorizing this MOE gives us the contingency table found in Table 6. At $\alpha = .10$ we would fail to reject the null hypothesis that the probability of being in class *j* is the same for all populations (none, air and air/grnd).

C. MOE 3: FRATRICIDE

Fratricide is the percentage of blue forces lost to friendly fire. Figure 17 shows the distribution of fratricide does not appear normal. In fact, only Strykers were ever lost to fratricide. No dismounts or other vehicles were lost this way. In every observation, either no Strykers were lost, one was lost, or two were lost.

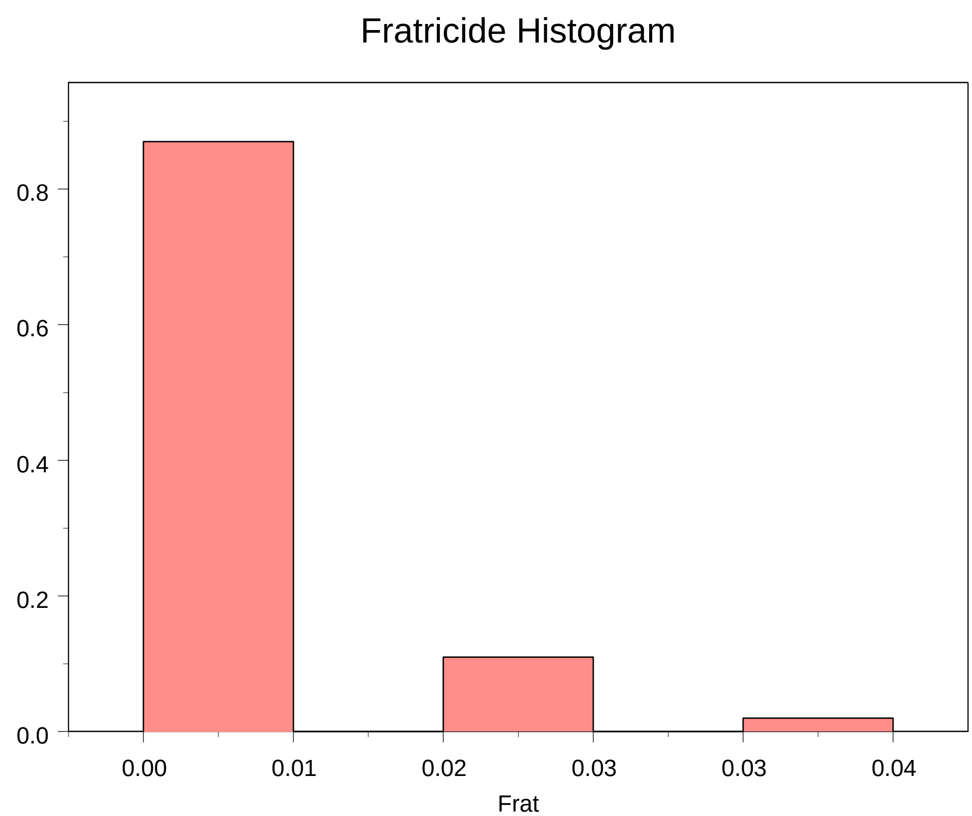

Figure 17. Distribution of Fratricide

Table 6. Fratricide by AJCN

AJCN / Blue Forces Killed	0	1	2
None	19	1	0
Air	33	6	1
Air/Grnd	35	4	1

Because we had a limited number of values, we decided to categorize our responses into three categories: those where no blue forces were lost to fratricide, those where one vehicle was lost, and those where two vehicles were lost. Assigning those responses by AJCN gave us Table 6. A Chi-squared test for homogeneity on this table gave us a p-value of .73 indicating the probability of being in class *j* (no blue forces lost to fratricide, 1 lost or 2 lost) is the same regardless of the type of AJCN present (none, air, or air/grnd). The Chi-squared test assumes a Chi-squared distribution. However, if the expected value of each cell (E_{ij}) is "fairly large", the value for α is a good approximation.

Conover (1999) says that the E_{ij} may be as small as .5, if most are greater than one, "without endangering the validity of the test."

We tried collapsing the rows table to distinguish a difference between no AJCN or any AJCN. This gave us a p-value of .47. Collapsing the columns of the table to try to distinguish between no fratricide and any fratricide gave us a p-value of .39. Under any reasonable α we would still fail the reject the null hypothesis.

D. MOE 4: ACQUISITION RATE

Acquisition rate is the number of red forces detected divided by the total number of red forces. For this MOE, we were concerned with the raw number of forces and not their aggregate firepower score. A red force could be detected more than once. If a unit was detected, then lost by all blue forces, then detected again, that counted as two detections.

The best model to predict acquisition rate is:

$$E(X_{i,j,k}) = .94 - .21 * \alpha_{SOF} - .15 * \beta_{None} - .06 * \beta_{Air/Grnd} - .21 * \delta_{Std}$$

Chapter III contains detailed analysis of this MOE. Table 7 contains the complete S-PLUS output for our model.

Table 7. ANOVA Output for Acquisition Rate

```
       *** Analysis of Variance Model ***
       Short Output:
       Call:
          aov(formula = AcqRateSqrt ~ Red + AJCN + FOW, data = poa.out, qr = T,
na.action = na.exclude)
       Terms:
                            Red     AJCN      FOW Residuals
        Sum of Squares 1.104037 0.318895 1.114913  1.585716
       Deg. of Freedom        1        2        1        95

       Residual standard error: 0.1291966
       Estimated effects may be unbalanced

       Type III Sum of Squares
                 Df Sum of Sq  Mean Sq  F Value        Pr(F)
             Red  1  1.104037 1.104037 66.14264 0.0000000000
            AJCN  2  0.318895 0.159447  9.55247 0.0001659248
             FOW  1  1.114913 1.114913 66.79424 0.0000000000
       Residuals 95  1.585716 0.016692

       Estimated K Coefficients for K-level Factor:
       $"(Intercept)":
        (Intercept)
          0.9429254
       $Red:
        CIS        SOF
          0 -0.2101463
       $AJCN:
        Air    Air/Grnd       None
          0 -0.06013119 -0.1542076
       $FOW:
        3        Std
        0 -0.2111789

       Tables of means
       Grand mean
       0.67737

        Red
              CIS    SOF
            0.782  0.572
       rep 50.000 50.000

        AJCN
              Air Air/Grnd   None
            0.732  0.672    0.578
       rep 40.000 40.000   20.000

        FOW
                3    Std
            0.783  0.572
rep 50.000 50.000
```

E. MOE 5: SURVIVABILITY

Survivability is the percentage of AJCN destroyed during the mission. We defined a destroyed AJCN as one destroyed by fires: either friendly or enemy. We assumed that maintenance problems will be standard across each platform and can be disregarded for this analysis. This MOE is only evaluated for those scenarios that had AJCN present. The distribution of survivability is not normal (Figure 18). In fact, it takes on only 5 values (0, .25, .33, .50 and .67).

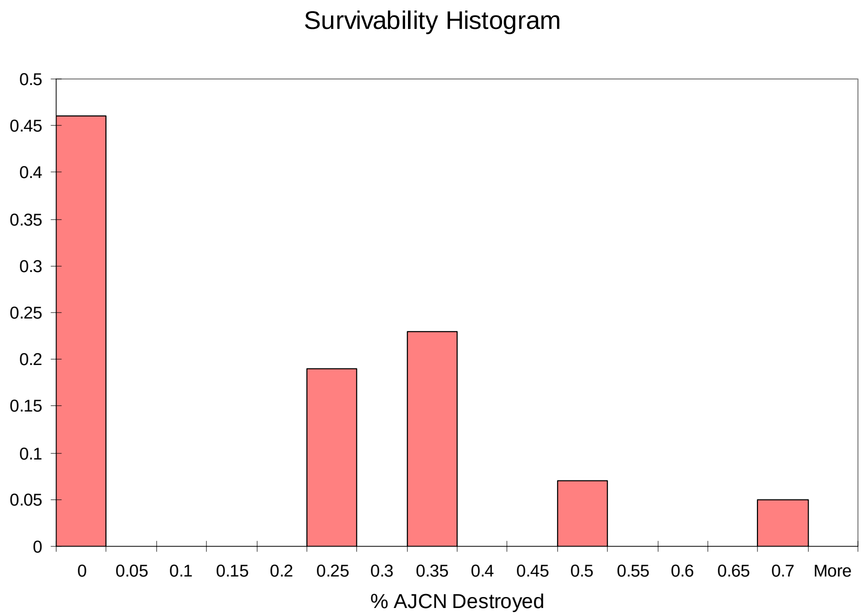

Figure 18. Distribution of Survivability

We conducted ANOVA and discovered what we suspected. Our residuals were not normally distributed (Figure 19).

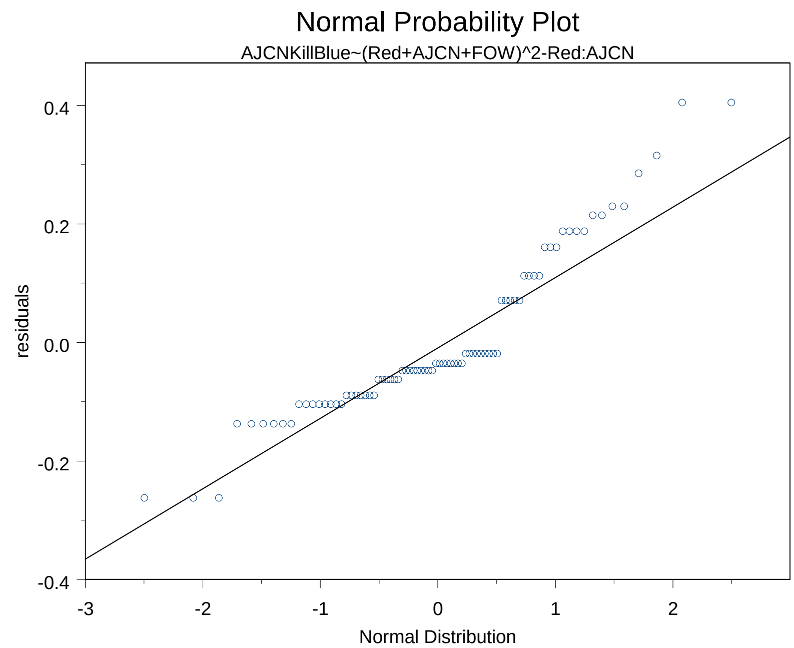

Figure 19. Normal Probability Plot: AJCNKillBlue~Red*AJCN*FOW-Red:AJCN

Table 8. AJCN Destroyed by AJCN

AJCN / AJCN Destroyed	0	1	2
Air	12	23	5
Air/Grnd	14	19	7

Again, we categorized AJCN survivability into three categories: no AJCN destroyed, 1 AJCN destroyed, or 2 AJCN destroyed. The results are shown in Table 8. A Chi-squared test on this table gave us a p-value of .65. We fail to reject the null hypothesis that the number of AJCN destroyed is the same for both populations (air and air/grnd) under any reasonable α .

We also constructed a contingency table separated by OComm level (Table 9). A Chi-squared test on this table gave us a p-value of .60. Again, under any reasonable α , we fail to reject the null hypothesis that the number of AJCN destroyed the same for all populations.

Table 9. AJCN Destroyed by OComm

OComm / AJCN Destroyed	0	1	2
Air.Voice	5	11	4
Air.Voice+Data	7	12	1
Air/Grnd.Voice	8	10	2
Air/Grnd.Voice+Data	6	9	5

Even though we did not find that the addition of a ground platform aided survivability, we made one interesting observation. In our simulation no ground platforms were ever lost. Although the ground platform's capabilities were limited by terrain, they were generally less vulnerable than a low-altitude aircraft.

F. MOE 6: JAMMING RATE

When analyzing jamming rate, we looked only at the cases where FOW was set to three. When FOW was standard, all forces had perfect information about all other friendly forces and when one unit knew information about an enemy unit, all friendly units knew the same information. The effect is that no messages were sent. It makes sense to analyze only the cases where a positive number of messages were sent. Therefore we did not include those cases where FOW was standard. A histogram of successful jamming rate shows that the data does not appear to be normal (Figure 20). Again, a large number of our observations were zero.

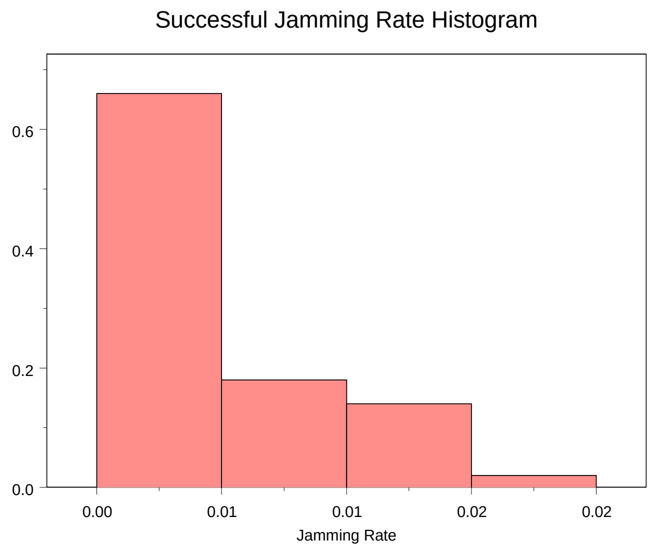

Figure 20. Distribution of Successful Jamming Rate

Analysis of variance confirms what we suspected: jamming rate residuals are not normally distributed (Figure 21).

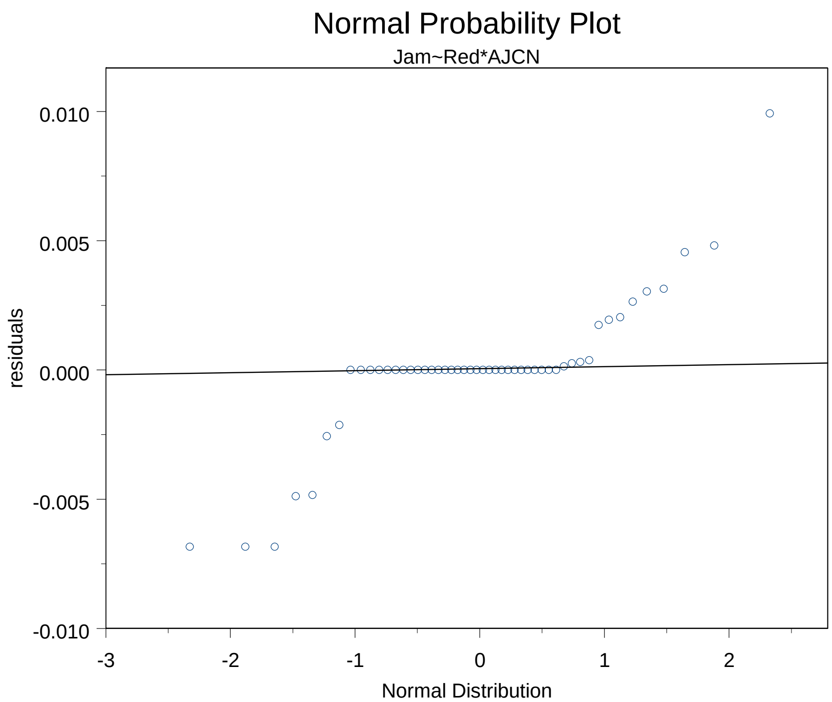

Figure 21. Normal Probability Plot: Jan~Red*AJCN

Table 10. Jamming by AJCN

AJCN / Jamming?	Yes	No
Air	0	20
Air/Grnd	17	3

Here it also seemed appropriate to categorize our response into two categories: jamming occurs and jamming does not occur (Table 11). A Chi-squared test on this table gives us a p-value of 0. We would reject the null hypothesis that all of the probabilities in the same column are equal to each other and conclude that at least one population is different. This seems like a logical conclusion given that the only scenarios in which jamming occurs are those with a ground platform present (Figure 22). Whether or not jamming occurs is independent of the type of communications capabilities present (voice or voice+data).

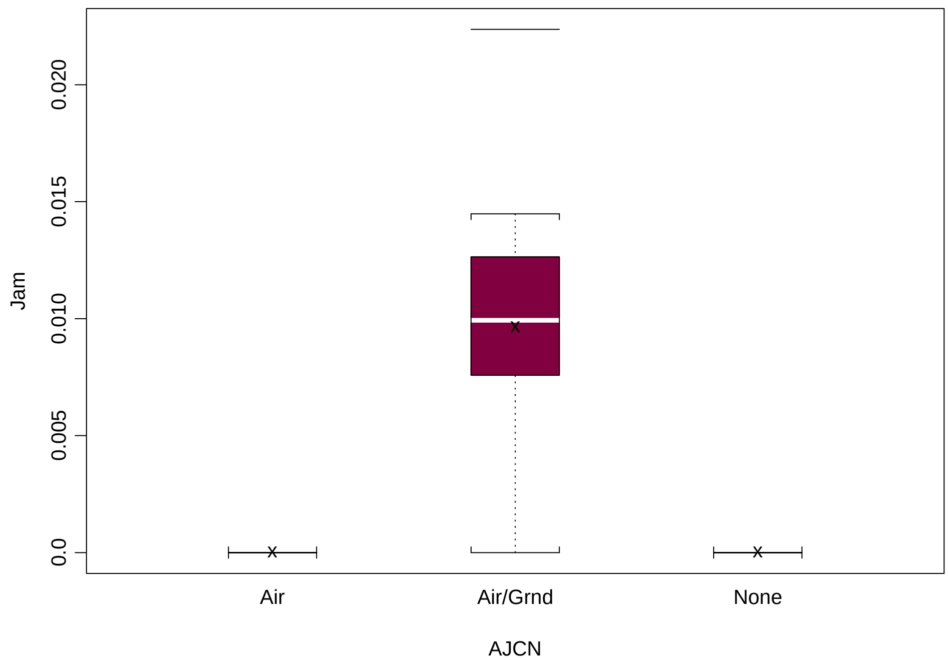

Figure 22. Boxplot of Successful Jamming Rate by AJCN

Another result is that the rate of jamming went up significantly when the red forces were conventional. This is also not surprising. Even though the insurgent forces were equipped with rudimentary communications equipment that was easily jammed, their range was very limited. It is likely that they would often not be within range of an AJCN to be jammed.

G. MOE 7: INTERCEPTION RATE

Again, when evaluating this MOE we used only the scenarios where FOW was set to three. We had a large number of zeros and data that appears non-normal (Figure 23). Residual plots of our ANOVA model confirm this.

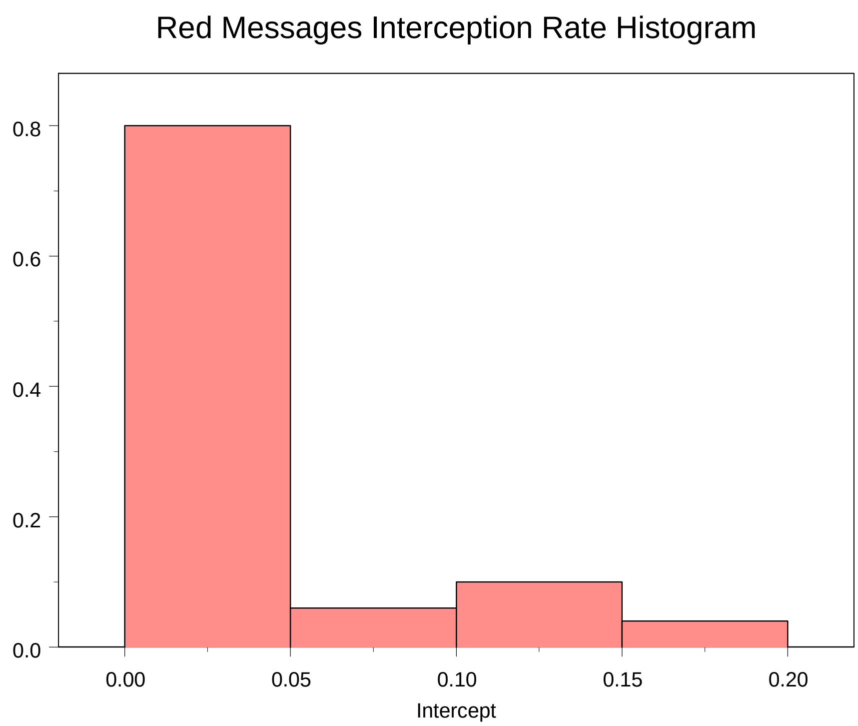

Figure 23. Distribution of Red Messages Interception Rate

Table 11. Interceptions by AJCN

AJCN / Intercepts?	Yes	No
Air	19	1
Air/Grnd	0	20

Here it also seemed appropriate to categorize our response into two categories: interceptions and no interceptions (Table 11). Not surprisingly, a Chi-squared test on this table gives us a p-value of 0. We would reject the null hypothesis that all of the probabilities in the same column are equal. The only scenarios in which interceptions occur are those with only air platforms present (Figure 24). Whether or not a scenario has interceptions is independent of the type of communications capabilities present (voice or voice+data).

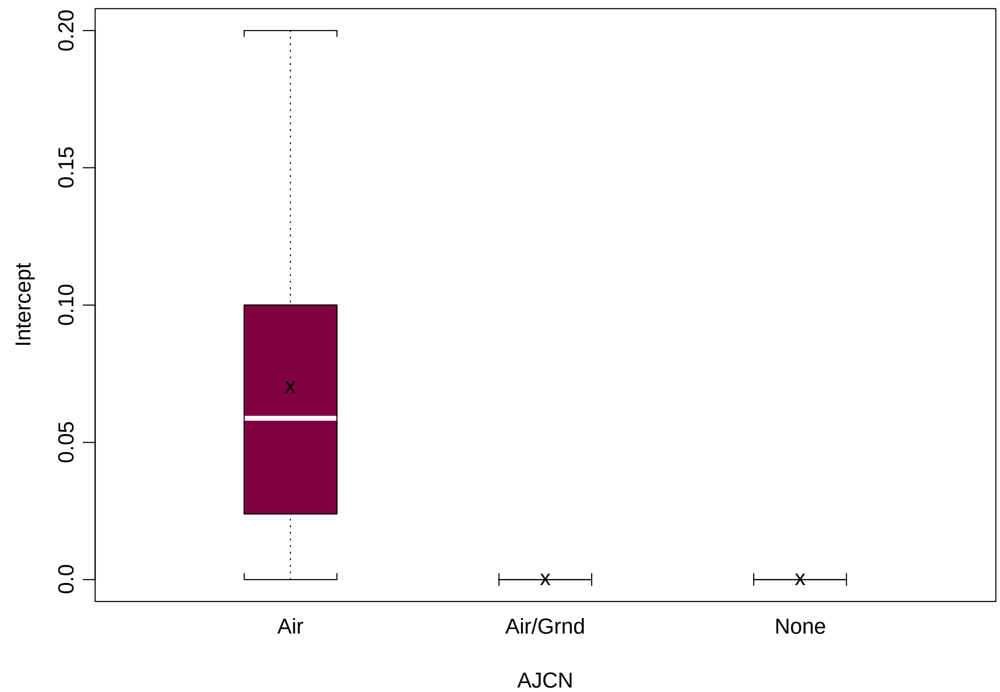

Figure 24. Boxplot of Interception Rate by AJCN

The rate of interceptions also went up significantly when the red forces were conventional, likely due to the limited range of the insurgents' communications equipment.

H. MOE 8: TIME

The time to complete mission is defined as the simulation time when the first blue force reaches the objective. It is measured in 30-second increments. After analyzing our simulation results, we discovered that this time never varied more than 30 seconds.

Statistical tests show that the addition of AJCN significantly lowered the mean time on objective. Figure 25 shows the average time on objective by AJCN. Note that the vertical scale is in seconds, so the mean for "Air" is less than 20 seconds faster than the mean for "Air/Grnd." Although this is statistically significant, it is not likely to be militarily significant.

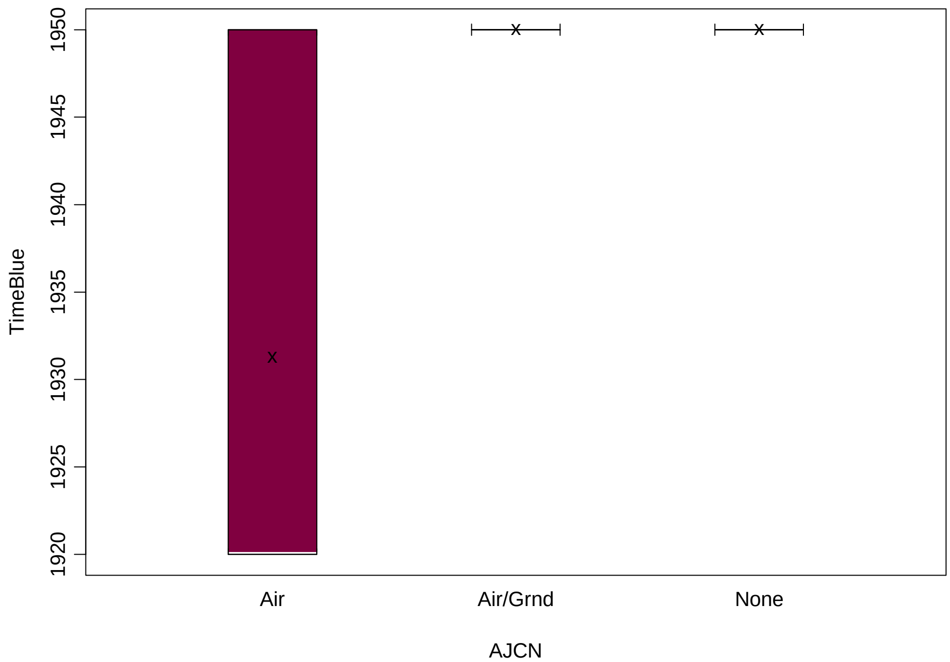

Figure 25. Boxplot of Time to Mission Completion by AJCN

The low variance can be explained by the scenario. Because the blue forces were never overwhelmed by the red forces, they continued to move toward the objective and the first force reached the objective at approximately the same time each time the scenario was run. If the scenario had had an overwhelming red force, this would likely not have been the case. Additionally, in real life a unit might chose to stop and aid its casualties instead of continuing on to the objective. Another way to define this MOE would be to record the time when 100% of all forces that eventually reach the objective, reach the objective. This would likely show more variance.

I. MOE 9: PERSISTENCE

At first look, it appeared that the AJCN significantly increased blue force persistence. The number of blue forces (in firepower score) remaining at mission completion was significantly higher when AJCN were present (Figure 26).

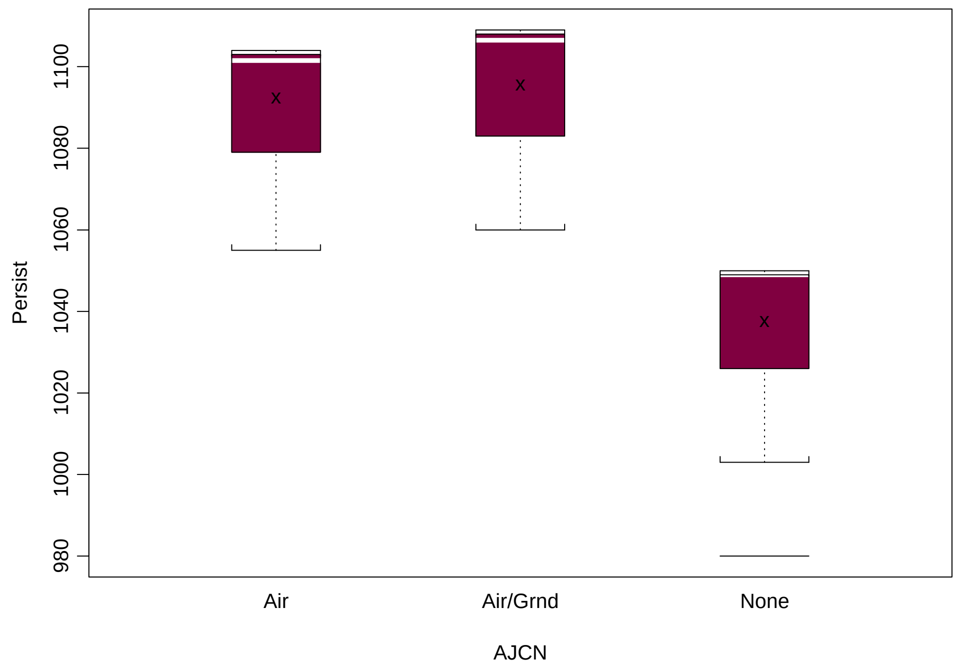

Figure 26. Boxplot of Persistence by AJCN

However, this data is misleading because more blue forces were also present at the start of the mission in scenarios with AJCN. For example, the blue forces with no AJCN had a firepower score of approximately 1049. This increased to 1108 when we added both air and ground AJCN. After considering this, a more useful measure for our scenario is the number of ground forces left at mission completion (we have no air forces other than the AJCN platforms). Figure 27 shows this distribution.

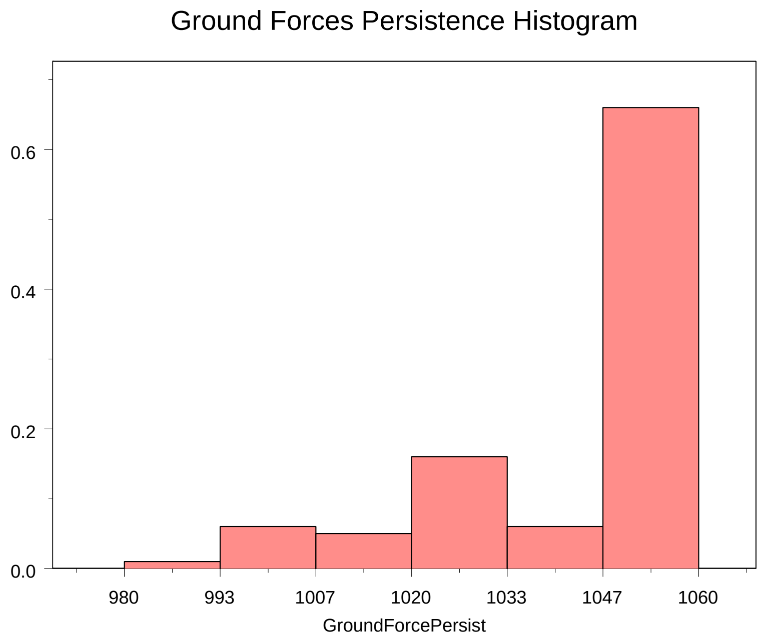

Figure 27. Distribution of Ground Forces Persistence

Another possible useful MOE would be the percentage of forces persisting to mission completion. This MOE is depicted in Figure 28.

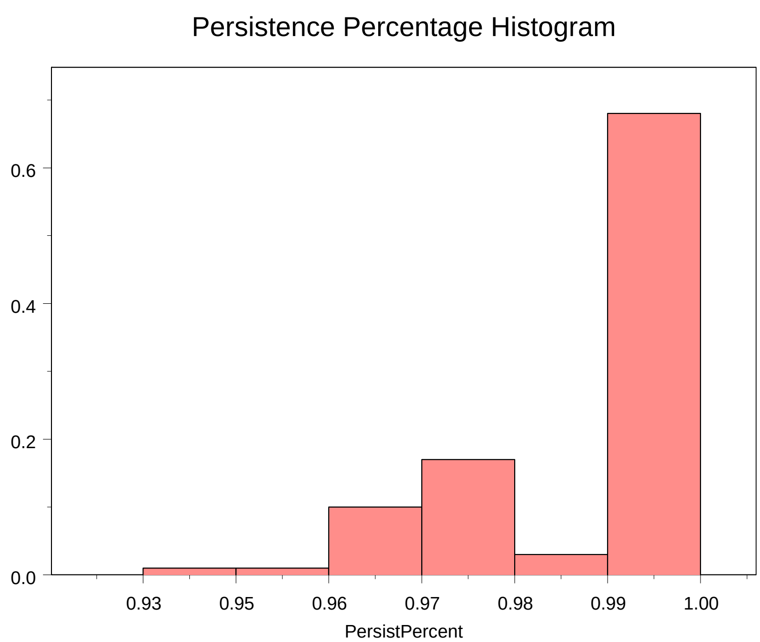

Figure 28. Distribution of Persistence Percentage

With these two MOE (ground force persistence and persistence percentage), we could not find any relationship between persistence and AJCN, Comms or OComm.

J. MOE 10: AVERAGE MESSAGE TRANSMITTAL TIME

Once again, for this portion of our analysis, we used only the scenarios with FOW set to three. Figure 29 shows the distribution of transmittal time. This data appears to be approximately normal.

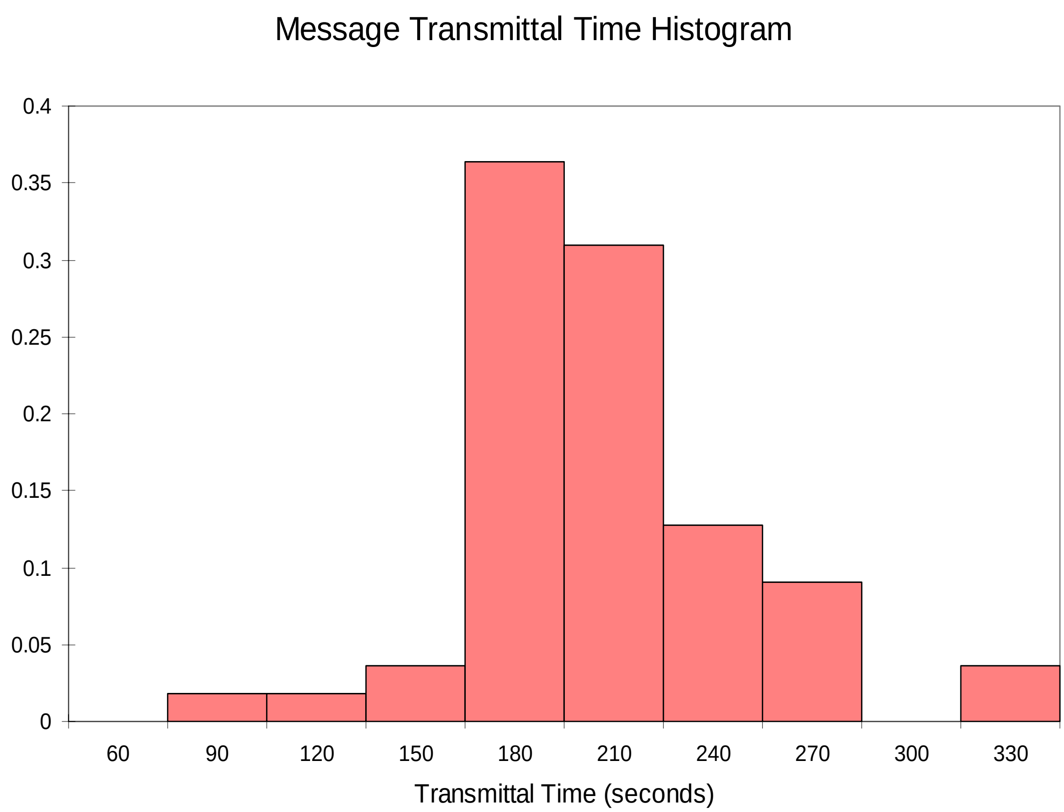

Figure 29. Distribution of Message Transmittal Time

ANOVA gives us the following model:

$$E(X_i) = 180.67 + 41.41 * \alpha_{None} - 10.72 * \alpha_{Air/Grnd} \tag{15}$$

This model produces residuals that appear to be both normal and homoscedastic (Figures 30 and 31).

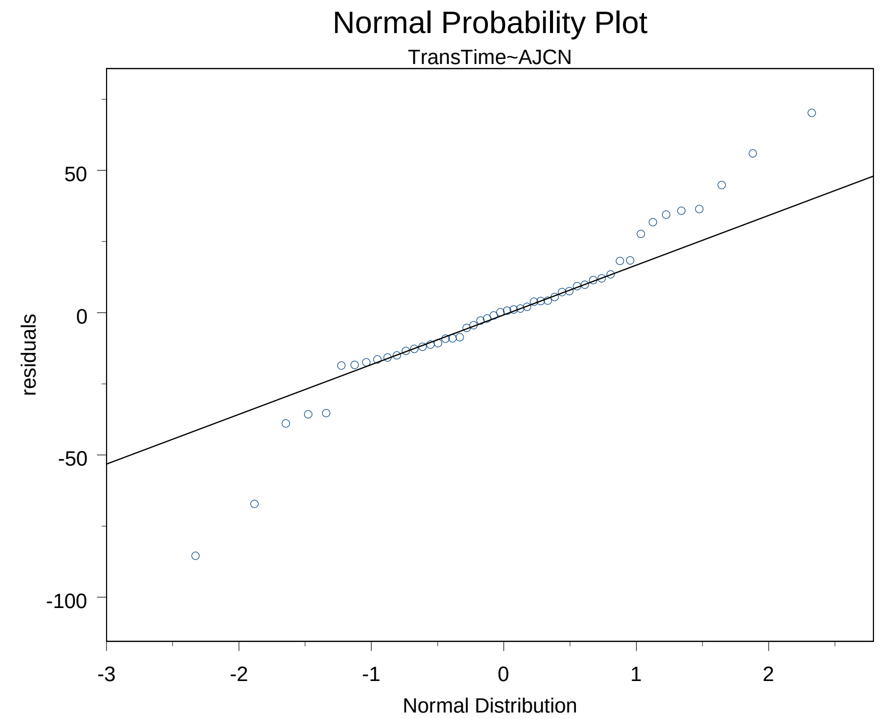

Figure 30. Normal Probability Plot: TransTime~AJCN

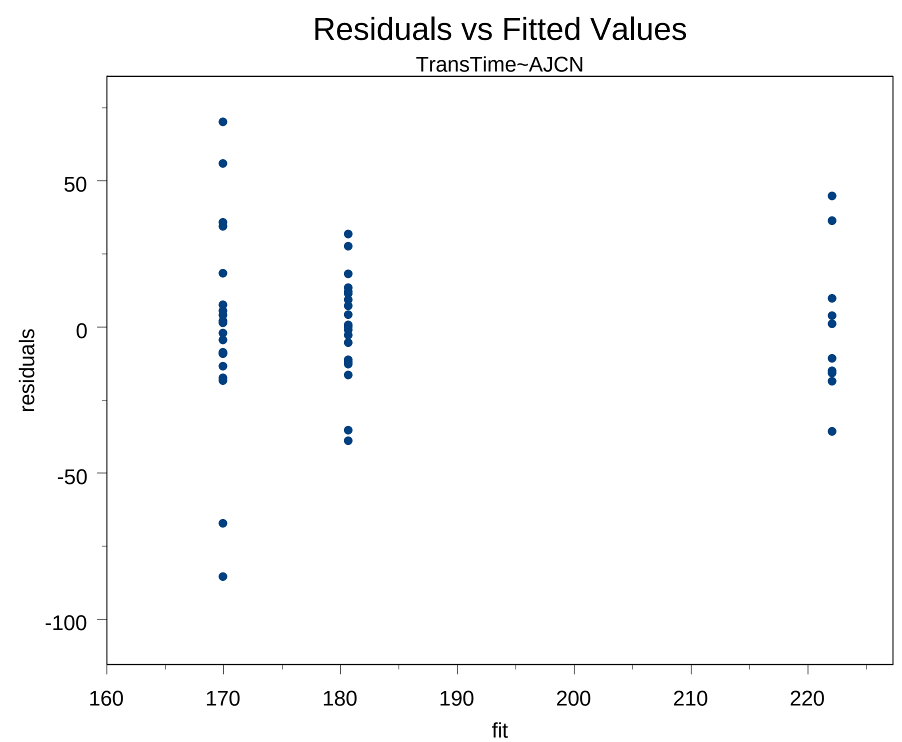

Figure 31. e_i vs $\hat{y}_i$: Message Transmittal Time~AJCN

Table 12. Avg Msg Trans Time by AJCN

AJCN	Avg Msg Trans Time
None	222
Air	181
Air/Grnd	170

Having any AJCN present significantly decreased the average message transmittal time. The average time to transmit a message without an AJCN was approximately 222 seconds. When an AJCN was present, that time decreased to 175 seconds – almost a minute faster. The average time when only air platforms were present was 181 seconds. That time decreased by over ten seconds with the addition of a ground platform (Figure 32 and Table 12).

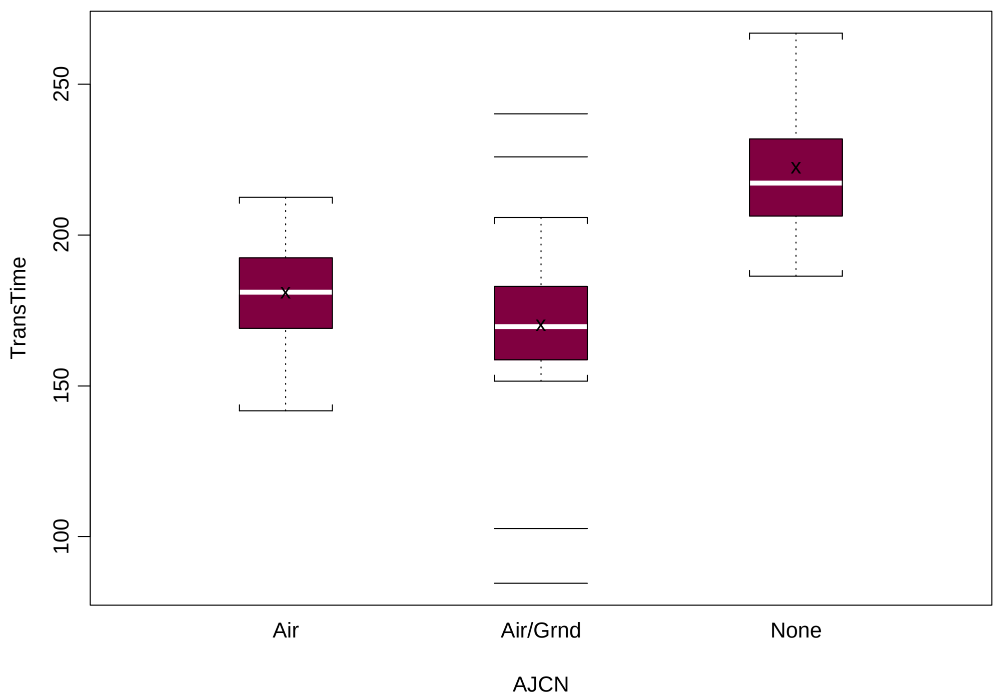

Figure 32. Boxplot of Message Transmittal Time by AJCN

Having both air and ground platforms present slightly decreased the average transmittal time over only air platforms but the result was not statistically significant (Figure 33).

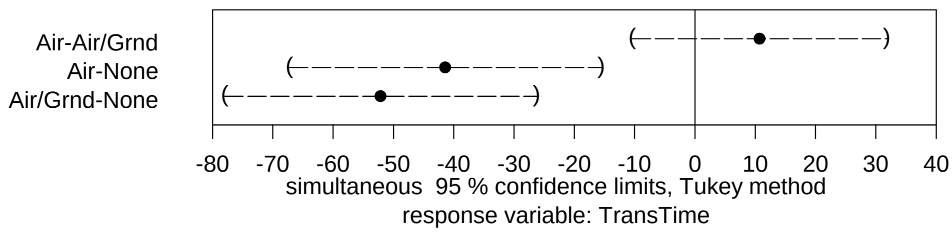

Figure 33. 95% Confidence Interval for Mean Transmittal Time by AJCN

Table 13 contains the S-PLUS output for this model.

Table 13. ANOVA Output for Message Transmittal Time

```
*** Analysis of Variance Model ***
Short Output:
Call:
   aov(formula = TransTime ~ AJCN, data = poa.out.jammable, qr = T,
na.action = na.exclude)
Terms:
                    AJCN Residuals
 Sum of Squares 18643.37  35756.48
Deg. of Freedom        2        47

Residual standard error: 27.58217
Estimated effects may be unbalanced

Type III Sum of Squares
          Df Sum of Sq  Mean Sq  F Value         Pr(F)
     AJCN  2  18643.37 9321.683 12.25286 0.00005215446
Residuals 47  35756.48  760.776

Estimated K Coefficients for K-level Factor:
$"(Intercept)":
 (Intercept)
     180.665
$AJCN:
 Air Air/Grnd     None
   0 -10.7152 41.40671

Tables of means
Grand mean

 184.66

 AJCN
       Air Air/Grnd   None
    180.66 169.95   222.07
rep  20.00  20.00    10.00
```

K. MOE 11: FAILED MESSAGES

To evaluate the number of failed messages, we used only those scenarios where messages were actually sent, which was when FOW was set to three. Figure 34 depicts failed messages.

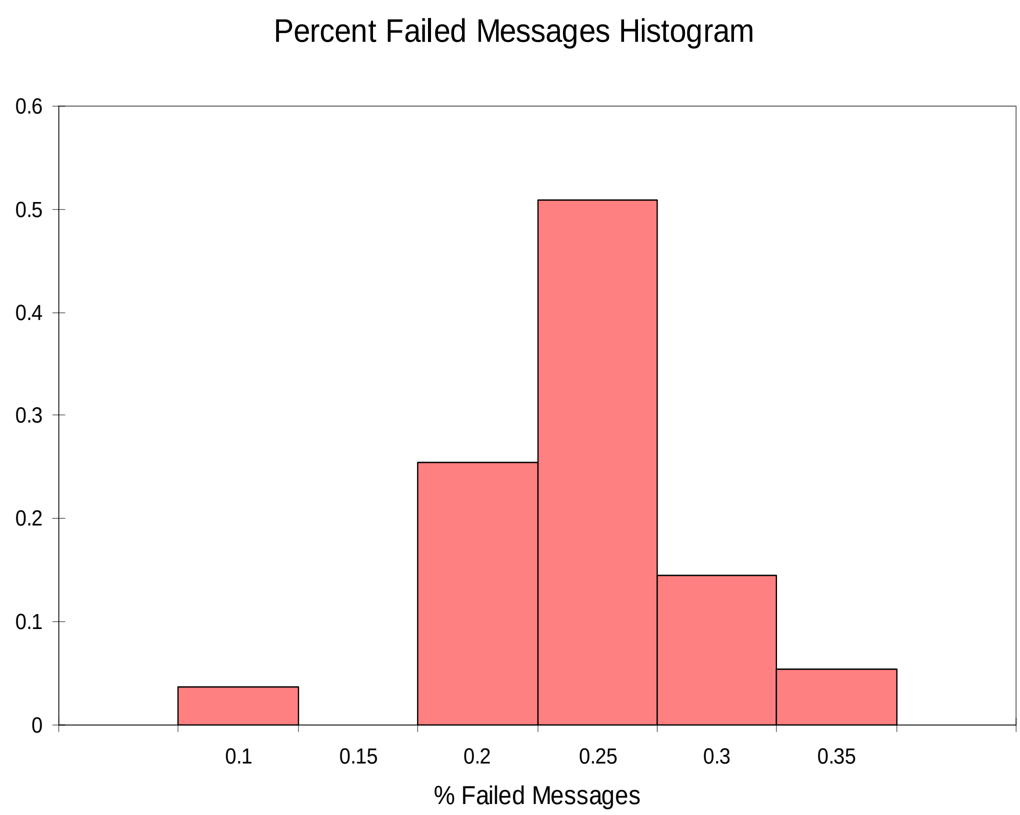

Figure 34. Distribution of Percent Failed Messages

ANOVA on failed messages gave us the following model:

$$E(X_{i,j}) = .19 + .022 * \alpha_{SOF} + .056 * \beta_{None} + .022 * \beta_{Air/Grnd} - .062 * \gamma_{SOF,Air/Grnd} - .002\gamma_{SOF,None} \quad (16)$$

The diagnostic plots for this model look good (Figures 35 and 36).

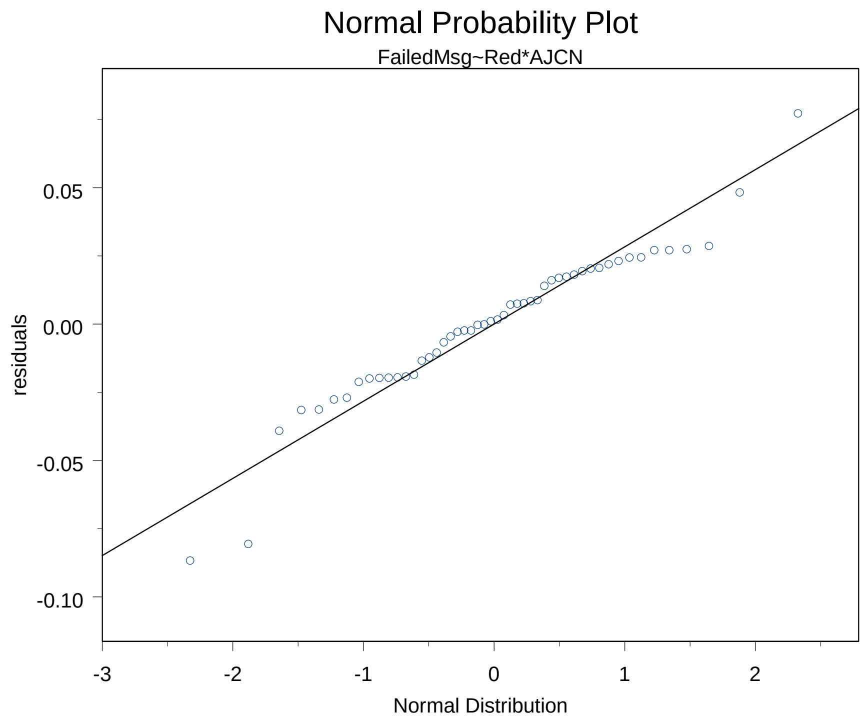

Figure 35. Normal Probability Plot: FailedMsg~Red*AJCN

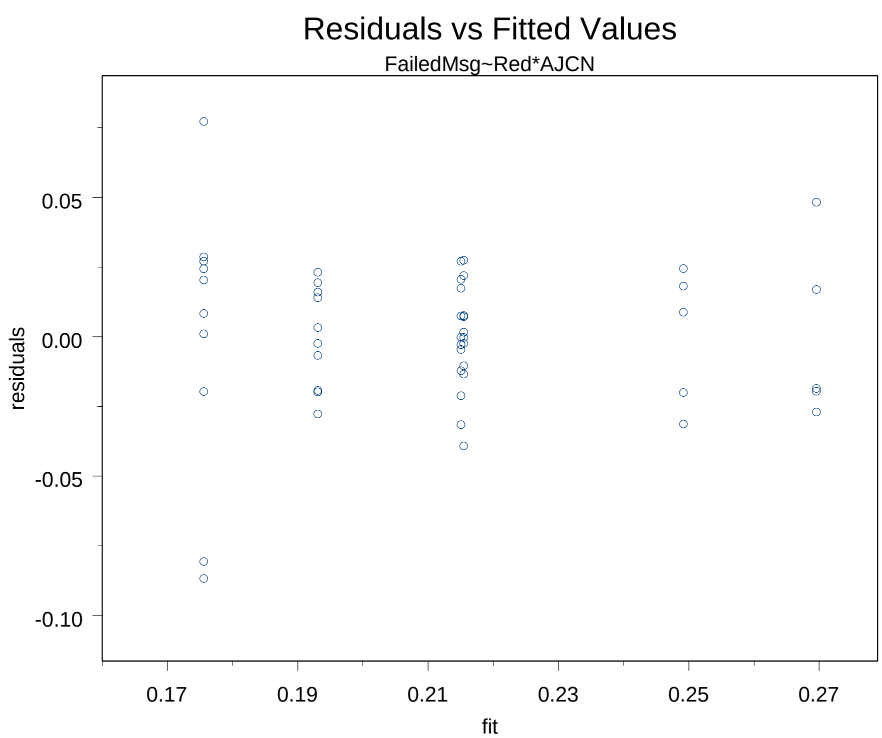

Figure 36. e_i vs $\hat{y}_i$: Failed Messages~Red*AJCN

Table 14. % Failed Msgs by AJCN

AJCN	%Failed Msgs
None	25.9
Air	20.4
Air/Grnd	19.5

The presence of AJCN significantly decreased the number of failed messages (Figure 37 and Table 14).

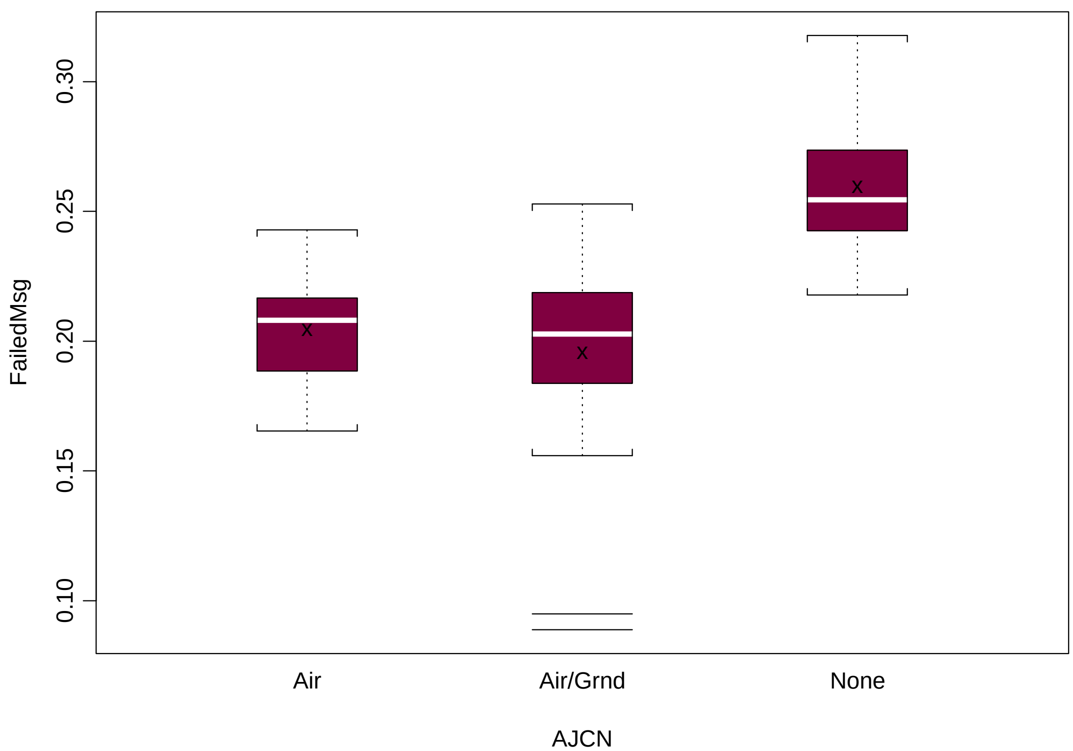

Figure 37. Boxplot of Percent Failed Messages by AJCN

Having both air and ground platforms present slightly decreased the number of failed messages over only air platforms but the result was not statistically significant (Figure 38).

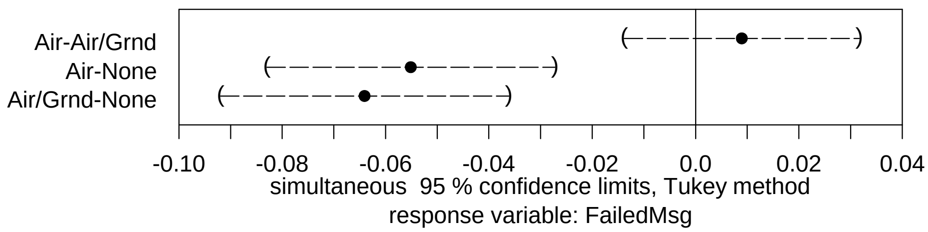

Figure 38. 95% Confidence Interval for Mean Failure Rate by AJCN

There is also significant interaction between the type of red forces and the types of AJCN present. Figure 39 shows that against an insurgent force when both air and ground platforms were present, the number of failed messages was decreased even more.

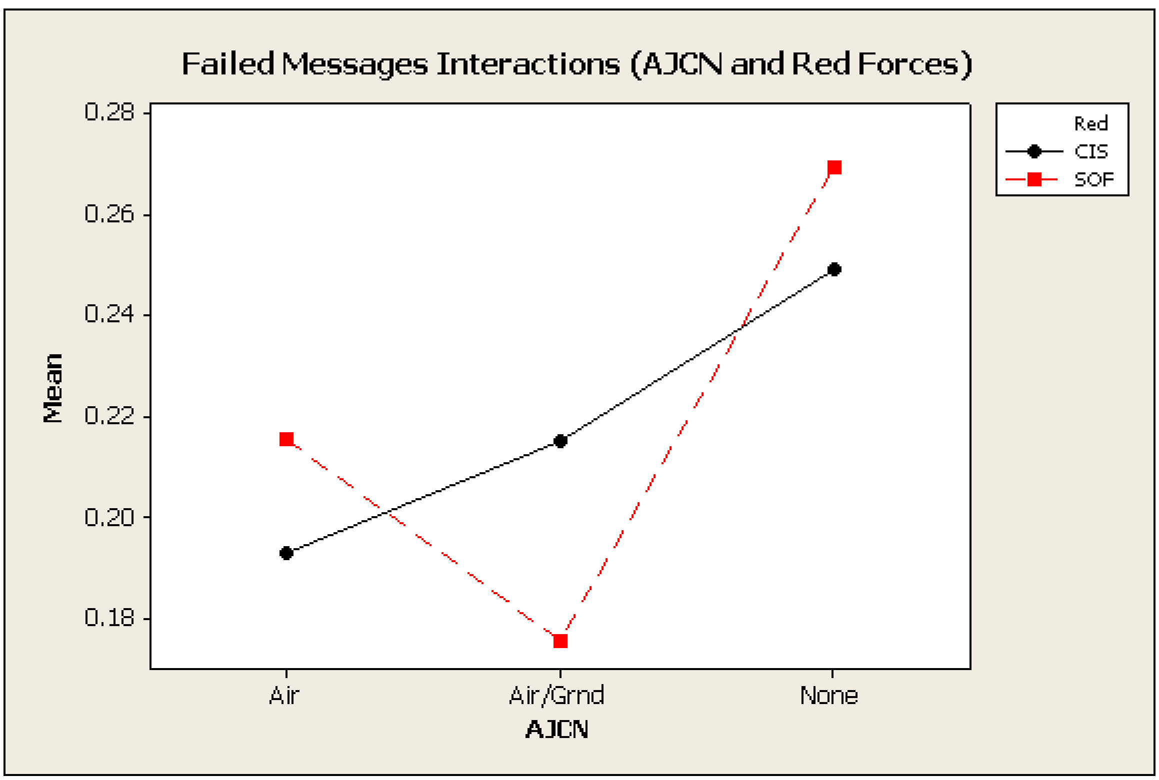

Figure 39. Failed Messages Interactions (AJCN and Red Forces)

Table 15 is the ANOVA output for this model.

Table 15. ANOVA Output for Percent Failed Messages

```
*** Analysis of Variance Model ***
Short Output:
Call:
   aov(formula = FailedMsg ~ (Red + AJCN)^2, data = poa.out.jammable, qr
= T, na.action = na.exclude)
Terms:
                       Red       AJCN   Red:AJCN  Residuals
 Sum of Squares 0.00009461 0.02918515 0.01123545 0.03875708
Deg. of Freedom          1          2          2         44
Residual standard error: 0.029679
Estimated effects may be unbalanced

Type III Sum of Squares
          Df  Sum of Sq    Mean Sq  F Value     Pr(F)
      Red  1 0.00001372 0.00001372  0.01557 0.9012569
     AJCN  2 0.02918515 0.01459257 16.56660 0.0000043
 Red:AJCN  2 0.01123545 0.00561772  6.37767 0.0036967
Residuals 44 0.03875708 0.00088084

Estimated K Coefficients for K-level Factor:
$"(Intercept)":
 (Intercept)
   0.1930823
$Red:
 CIS        SOF
   0 0.02239004
$AJCN:
 Air   Air/Grnd       None
   0 0.02197367 0.05609401
$"Red:AJCN":
 CISAir SOFAir CISAir/Grnd SOFAir/Grnd CISNone      SOFNone
      0      0           0 -0.06184884       0 -0.002008608

Tables of means
Grand mean
0.21171

 Red
      CIS    SOF
    0.213  0.210
rep 25.000 25.000

 AJCN
      Air Air/Grnd   None
    0.204  0.195    0.259
rep 20.000 20.000   10.000

 Red:AJCN
Dim 1 : Red
Dim 2 : AJCN
        Air Air/Grnd    None
CIS  0.1931  0.2151   0.2492
rep 10.0000 10.0000   5.0000
SOF  0.2155  0.1756   0.2696
rep 10.0000 10.0000   5.0000
```

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